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OCCUPANT EJECTION RESPONSE ANALYSIS OF FRONT vs. REAR CREW STATION IN TF-18 AIRCRAFT

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Technical Report

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BACKGROUND

Due to differences in the geometry of the rear and front crew stations in the TF-18 aircraft, there is some concern regarding occupant-seat interaction in the aft crew station. Specifically, rudder adjustment in the aft location was reduced by 1.75" over that existing in the front. This reduction in rudder adjustment might affect seat-man compliance and consequently occupant response to ejection forces. A change in occupant response could compromise the effectiveness of the toe guides in reducing the probability of direct impact between the feet and instrument panel. Since all other critical clearance dimensions are the same in the respective crew stations, the only occupants of concern are those that require that additional 1.75" of rudder adjustment. These large individuals however, are also the ones that require the greater protection, being the ones most likely to experience foot-instrument panel contact. The questions to be answered are:

1. Is there a difference in ejection response of large individuals in the front vs. the rear crew station?

2. Can anthropometric limitations be specified such that the possible response differences can be obviated?

METHOD

The respective crew stations were digitized and, given the existing geometry, a large occupant (98% Sitting Knee Height and Buttock to Knee length) was simulated and positioned in the front crew station, using the Bioman Computer Program. This "STANDARD" occupant was perfectly accomodated in the front seat (optimized restraint, rudders full forward, seat full down and thighs in contact with the seat pan). An ejection was modeled using previously obtained seat-time histories (1). Simulation runs with and without toe guides were conducted. Employing the same occupant anthropometry, ejections from the aft crew station (with and without toe guides) were compared to the results obtained from the front location and differences in occupant response noted. Subsequently, leg link lengths (Sitting Knee Height and Buttock to Knee Length) were adjusted to again obtain perfect seat-man compliance and to

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be comparable to results obtained for the forward crew station. It should be noted that this approach considered the forward crew station to be the norm and that the results discussed deal only with getting the response of the rear occupant similar to that of the front and consequently be subject to the same ejection risks.

The following analysis is based on some crucial assumptions, which if not adhered to, might preclude its validity. Although all the relative relationships and trends discussed would still be correct, the numerical values derived could be biased. These assumptions are as follows:

th percentile

1. A 98% (Buttock to Knee and Sitting Knee Height) subject can be accomodated in the forward crew station. This implies that with the rudder pedals adjusted full forward, such an individual will have his thighs supported by the seat pan. This is the prescribed pre-ejection position.

2. The occupant, when properly seated, will have his buttocks and thoracic region in contact with the Seat Back Tangent Line.

3. Toe guides effectively change foot trajectory to alleviate foot-instrument panel contact. Furthermore, they work equally well for all individuals, no matter what the anthropometry.

Some comments regarding these basic assumptions must be made. The crew station dimensions and seat geometry were determined from technical drawings (2,3). Given these dimensions, the STANDARD configuration of the occupant, based on 98% link lengths as defined by the 1964 Survey of Naval Aviators was found to be accomodated in the front crew station (4). These link lengths were in good agreement with those specified in MS-1333A (5). During the tower tests conducted by NADC, with full front crew station mock-up, subject "F" required a rudder adjustment that exceeded the maximum available for the aircraft configuration (6). Since his Sitting Knee Height (96%) and Buttock to Knee Length (98%) did not exceed those modeled, he should have been accomodated. For this individual, the seat was adjusted upward (sitting above Design Eye Plane) in order to obtain thigh-seat pan contact as an initial position for the tower ejection. The implications from this are two-fold:

1. Girth of the thighs and thickness of the gluteal region determines how high above the seat pan the hip is localized. One notes that as the Thigh Clearance (figure 1, dimension 21) gets smaller, the hip will tend to come closer to the seat pan and increased rudder adjustment is required to maintain thigh-seat pan contact. Consequently, it could be possible that the Thigh Clearance (and therefore the normal distance from the hip to the seat pan) was overestimated in the simulations. Unfortunately, this dimension was not included in the Naval Anthropometry, or obtained for the subject in question.

2. We have assumed that the occupant sits against the Seat Back Tangent Line. If in fact this is not the case and the occupant is relocated somewhat forward, then his knee and rudder location would have to be compensated an equal amount to maintain the assumed seating geometry. If rudder adjustment is unavailable, then the thighs will be raised off the seat pan. This is the more likely situation of the two described.

Regarding assumption 3, some qualifications should be pointed out. A series of 10 tower ejections, employing a cross section of human subjects available, was run at NADC to evaluate the proposed toe guide configuration. Simulation and test results showed that the toe guides influenced the site of contact with the instrument panel, moving the contact point toward the toe. It was also apparent from the analysis that the toe guides were not completely effective, since some of the subjects did not fully engage them and in two cases missed the guides entirely (7,8). In terms of physiological consequences, if moving the contact point toward the tip of the shoe reduces the potential for injury, then the toe guides are a viable means for such a reduction.

Given the assumptions listed and possible variations from them as discussed, this analysis reduces to establishing whether thigh elevation changes toe guide engagement and the probability of impact. In effect one is looking for anthropometric limitations which, if applied to the rear occupant, will assure "functional replication" (i.e. his lower leg and foot will respond in the same way).

Figures 2A and 3A show the same STANDARD occupant sitting in the front and aft crew stations respectively. For the aft seating geometry, given the link lengths employed, thigh elevation off the seat pan is clearly evident. A "functional replication" of the front seating geometry can be obtained in three ways:

1. Raise the seat.

2. Shorten the Buttock to Knee Length.

3. Shorten the Sitting Knee Height.

Raising the seat must be approached with caution since, for individuals with large trunks, this might elevate the occupant above the Design Eye Plane resulting with possible pre-loading of the spine and degraded cervical spine alignment during ejection. Furthermore, such elevation might position the occupant's shoulders above the shoulder strap take up reels and, upon ejection, this powered inertia reel will decrease, reverse and pull downward on the thoracic spine.

Limitations placed on the Buttock to Knee Length and Sitting Knee Height can be effectively used to assure comparable results (seat-man

compliance) without other possibly adverse effects. The criteria to be proposed therefore should assure same seat-man interaction and minimize the number of subjects expected to be excluded from the flying population.

RESULTS

Thigh elevation above the seat pan has been found to increase the probability of foot strikes (9). Figure 2A shows the initial position of the STANDARD occupant in the front crew station. It will be noted that no toe guides were modeled in these initial runs since we were trying to analyze the response difference for large individuals in the front vs. the rear crew station. In these runs we did not want the toe guide-foot interaction to overshadow the response differences. Figure 2B shows the foot-instrument panel contact during ejection from the front crew station. Figure 2C shows the occupant response over the first 125 ms. The initial position of this STANDARD occupant in the aft crew station is shown in figure 3A. Moving the rudder pedals aft by 1.75" causes the thigh to be elevated off the seat pan. As before, foot contact is still evident at approximately 125 ms, into the ejection (figure 3B). It should be noted that the severety of the contact has not been reduced significantly, despite the fact that the foot has been moved aft by 1.75". It would appear that the advantageous effects expected by moving the feet aft (reducing probability of contact) have been cancelled by the detrimental effects of thigh elevation (increased probability of contact).

Keeping the foot in the same initial position for the rear crew station, one can obtain thigh-seat pan contact by shortening the Buttock to Knee Length (dimension 20-figure 1) by approximately 1.8". This revised initial position is shown in figure 4A. Since the initial position of the foot and the lower leg length remain the same from the previous run, the difference in occupant response is a function of thigh elevation. As can be seen from figure 4B, the probability of foot-instrument panel contact has been significantly reduced (figure 3B vs. 4B).

Another way of obtaining thigh-seat pan contact is leaving the Buttock to Knee Length the same but shortening the lower leg length (figure 5A). this was accomplished by reducing Sitting Knee Height (dimension 24-figure 1) by approximately 1.6". This revised anthropometry results in a substantial increase in contact probability (figure 5B) over that seen in figure 4B (short thigh) but not over that seen for the STANDARD occupant in the front crew station (figure 2B). It should be noted that in shortening the lower leg, its Center of Gravity is located closer to the knee (the pivot point for the lower leg) and consequently the torques created during ejection are smaller and the lower leg and foot (although supported by the seat pan) swing aft at a slower rate.

These results can be clearly seen from the following graphs which are coded as follows:

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CAA - STANDARD occupant in front crew station (no toe guides).

AQB - STANDARD occupant in rear crew station (no toe guides).

BZG - Short thigh in rear crew station (no toe guides).

ASI - Short lower leg in rear crew station (no toe guides).

Foot Center of Gravity (C.G.) response to the four cases listed above is shown in figure 6. It will be noted that the case where the thigh is not initially in contact with the seat pan has a significantly different acceleration profile and that the foot response is delayed by approximately 40 ms. This delay is due to the time taken for the thigh to come in contact with the seat pan as the seat moves up the rails. The two cases where the thigh is in contact with the seat pan and where the lower legs are of identical length, are virtually indestinguishable (CAA, BZG). Since foot response in these two cases is comparable and since, in case BZG, the foot is 1.75" aft of that in case CAA, the probability of foot-instrument panel interference is minimized (figure 4B). Run ASI, employing a shorter lower leg, shows some variation from the other two runs with initial thigh contact, due to the differences in torque at the knee, but the characteristic response is in keeping with the thigh contact situation. It will be noted that with the elevated thigh, the introduced delay results in elevated G levels attained and consequently a harder anticipated contact with the toe guide. It is clear from this figure that the effects of thigh elevation (change in seat-man interaction) overshadow those associated with changes in leg anthropometry. This conclusion is further demonstrated when looking at the foot angular acceleration (figure 7). Here results from varying link lengths with thigh support are identical, whereas same link lengths with differing thigh support (CAA vs. AQB) are clearly different.

The respective anticipated knee linear velocities are shown in figure 8. Again changes in seat-man interaction have a much more pronounced effect than changes in anthropometry. Clearly, thigh response is independent of length but not of its relative position to the seat pan. This interplay between thigh elevation and link length is further demonstrated in figure 9 (ankle linear velocity) and figure 10 (lower leg angular velocity). Again differing anthropometry with thigh support can be readily grouped, whereas thigh elevation clearly changes lower leg and foot response.

Given these results, it would appear that the anthropometric limitations placed on the rear occupant (shortened lower leg or shortened thigh) do result in a foot response very similar to that of a perfectly accomodated occupant in the front crew station. These results however do not imply that the probability of foot-instrument panel contact is unaffected and that one might not need the toe guides. Clearly there is a difference between figures 4B (short thigh) and 5B (short lower leg), but the contact severity does not appear to be worse than for the similar case in the front crew station (figure 2B).

The question to be posed is whether or not changes in initial foot position (1.75" aft in rear crew station) and changes in link lengths (to obtain similar foot response) alter the severity and probability of foot-toe guide contact. From the tower tests conducted, it was evident that the severity of contact (amount of deflection of toe guides seen at time of contact) and probability of contact (some occupants missed toe guides) was not uniform over the population tested. Since all human test subjects were perfectly accomodated, this change was due to variability in the individuals response, anthropometry, and initial position of the foot relative to the toe guides.

This difference in engaging the toe guides can be modeled in several ways. One can change the size of the foot. This however changes not only the probability of foot-toe guide contact but also the probability of foot-instrument panel contact. Changing the angular orientation of the foot relative to the toe guides is also unacceptable since it changes the initial position of the foot, making comparisons to other runs tenuous. Therefore, to look at differences in toe guide engagement and still maintain the same sizing of the foot and its initial position, the modeled toe guides were moved in relation to the foot and their size was changed to obtain a variety of foot-toe guide responses.

Using the front crew station and STANDARD occupant as the norm, the toe guide location (in relation to the rudder pedal) and its size (how far down the toes does it extend) was varied, keeping the initial position and orientation of all the segments the same. One can now look at the effects of various toe guide configurations, independent of occupant initial position. The coding for these runs was as follows:

CIT - Large toe guides (close to rudder pedal).

BVX - Short toe guides (close to rudder pedal).

FEG - Short toe guides (far from rudder pedal).

BGZ - Short toe guides (far out from rudder pedal).

Figure 11 (run CIT) shows the foot engaging the large toe guides which exert enough force on the foot (extending the foot relative to the lower leg) to alter the foot trajectory, resulting in clearance between the foot and instrument panel (compare to run CAA-figure 2B). Figure 12 (run BVX) has the toe guide in the identical location relative to the foot and rudder pedals but is shorter than in the previous case. The effectiveness of the toe guides is clearly reduced and foot-instrument panel contact is evident. Moving this size toe guide aft in relation to the rudder (figure 13-run FEG) further degrades results (in terms of foot- instrument panel contact) and the foot now barely comes in contact with the toe guide. Further movement of the toe guides (figure 14A) causes the toes to miss the toe guide altogether in this arrangement (figure 14B).

Occupant response to toe guide contact appears to be a local event. Figure 15 demonstrates that the hip response to ejection forces is not influenced to a great degree by the severity of toe guide engagement. The ankle time history also appears less sensitive than expected to the toe guide contact. In figure 16, only the large, close toe guide (CIT) appears descernably different from the other three cases. This is further substantiated by the ankle linear displacement (figure 17). Consequently, it would appear that the primary effect of the toe guide is in extending the ankle and consequently pointing the toes. This can be seen in figure 18 where the angular velocity of the foot varies with the respective toe guide arrangements, whereas the location of the ankle in the vehicle coordinate system remains relatively unchanged. This pointing of the toes gets them further away from the obstruction site (leading edge of the instrument panel), delaying the contact. With this additional time bought however, the lower leg is allowed to swing back further providing additional clearance. It would seem therefore that early and prolonged contact would maximize toe guide effectiveness. Extension of the toe guides and minimizing the distance to the rudder pedals would make improvement possible. Additionally, increasing their stiffness also could improve their effectivenss in pointing the toes.

We have already established that shortening the upper or the lower leg to attain the desired seat-man compliance makes occupant response in the rear seat comparable to that in the front. Using the far position of the toe guides the simulations were rerun to establish whether the toe guides are engaged in a differing fashion. The far position was chosen since contact was to be used as an relative indicator (presence or absence of contact) for comparison with the front crew station. It will be remembered that this far toe guide position resulted in minimal foot-toe guide contact in the front crew station and consequently very little effect on foot response.

Coding for the toe guide runs in the rear crew station were as follows:

EYM - STANDARD occupant (far toe guides).

FCM - Short lower leg (far toe guides).

BNI - Short thigh (far toe guides).

Figure 19 shows the STANDARD occupant in the rear crew station (thigh elevation) with the "far" toe guides. In this case, the foot barely missed the toe guides (vs. contact in the front crew station) and the results are directly comparable to case AQB (figure 3B). This result implies that changing seat man compliance (elevating the thigh off the seat pan) affects foot-toe guide interaction. If this possibility is allowed (thigh elevation) then the results from the tower tests cannot be be applied since in these tests initial seat pan-thigh contact was assured.

The case of the short lower leg in the rear crew station (run FCM) is shown in figure 20. As was the case in the front crew station, the toe guide was contacted but somewhat more effectively than was previously the case. Since with the shorter lower leg the foot swings back slower, contact was maintained for a longer time and additional clearance provided (compare to figure 5B).

Results from the short thigh case are shown in figure 21 and are comparable to those in the front crew station with minimal toe guide contact. This minimal contact leaves the foot trajectory essentially unchanged (compare to figure 4B).

Consequently it would appear that the anthropometric limitations described do provide comparable occupant responses to ejection in the respective TF-18 crew stations and do not alter the foot-toe guide interactions. If anything, some improvement can be anticipated.

DISCUSSION

The results described assumed a 98 percentile (additive) occupant seated in the respective crew stations with the seat in the full down position. This "additive" occupant (98% Buttock to Knee Length and 98% Sitting Knee Height) has a leg length representing less than the assumed 2% of the flying population (i.e. 98% lower leg added to a 98% upper leg is larger than a 98% leg length). Assuming such an individual is accomodated in the front crew station, one would have to shorten the Buttock to Knee Length or the Sitting Knee Height by approximately 1.8 or 1.6 inches respectively to achieve a comparable ejection response in the rear crew station.

Recalculating the initial seating position for a "additive" 99 percentile provided results in such close agreement with those of the 98% that they were within the accuracy of the simulations, given the number of unknowns that had to be estimated. Consequently the subsequent recommendations employ the 99% as the upper limit.

Additionally, the simulations considered only the extremes. That is, restrictions only on one dimension at a time. Therefore, the short thigh case would exclude all subjects with a Buttock to Knee Length in excess of the 75th. percentile (greater than 24.76"). In figure 22A this would correspond to a 24% reduction of the flying population that would fall into area ABGH. Likewise using the short lower leg limitation (Sitting Knee Height) all subjects falling into area CDGF would be rejected, accounting for a 22% reduction of the population.

Therefore, if one wished to use only one rejection criteria, one would choose Sitting Knee Height, since the same protection would be afforded with fewer candidates rejected (22% vs. 24%) If one were to use BOTH rejection criteria (Buttock to Knee and Knee Height) one could anticipate to eliminate approximately 30% (corresponding to area EFGH). It must be noted that areas ABGH and CFGD are not additive since area EFGH is counted twice. Estimates of the population in EFGH was obtained

from Maroney's Bivariate Tables (10). Using the dual criteria (Buttock to Knee not to exceed 24.76" and Knee height not to exceed 22.59") the rejection region would be area EFGH. The situations modeled correspond to point F (only Knee Height restrictions - short lower leg) and point H (only Buttock to Knee Length restrictions - short thigh). A subject can be accomodated however, by shortening both the thigh and lower leg. In fact, link length combinations lying along line FH should also be accomodated. Since this is the case, the rejection region now becomes area FGH. Since more individuals are expected to lie in area EFH (short Buttock to Knee, short Knee Height) than in area FGH (long Buttock to Knee, long Knee Height), less than 15% of the population is expected to be rejected. The rejection region is shown to the right of line FH in figure 22B.

It should be noted that line FH corresponds to the seat full down position which accomodates an individual with a sitting height of 34.21". If the seat need not be in the full down position, (Sitting Eye Height less than 98%) for a given individual, then longer leg links can become acceptable since additional thigh elevation can be compensated for by seat height adjustment. Consequently for such individuals, line FH can be moved to IJ. Unfortunately, tri-variate tables are questionable in validity, given the number of subjects used in the 1964 Anthropometric Survey, because the numbers in each cell become very small and statistical inference tenuous.

Additionally, upward seat adjustment to attain accomodation must be done with extreme caution. Sitting above the Design Eye Plane can have serious consequences. First, head to canopy clearances are affected. Secondly, since the head box is not parallel to the Seat Back, raising of the seat degrades cervical spine alignment. Thirdly, one must be sure that the shoulders are not adjusted to be above the shoulder strap take up reels. Consequently, Sitting Eye Height can not be used as an indicator without also considering Shoulder Sitting Height (dimension 19 - figure 1).

It is fully realized that pilots have a tendency to sit above the Design Eye Plane. One has little control over pilot preferences. The pilots however should be made aware of the risks and must be provided with the option to be able to sit at the Design Eye Plane without compromising safety during an emergency escape. Finally, only seat-man compliance has been addressed in this report. Knee and shin to instrument panel clearances have not been analyzed in detail for the occupants considered. It would appear however that with the thighs full down on the seat bucket, these clearances would be maximized for the individuals in question.

CONCLUSIONS

1. Thigh elevation off the seat pan degrades occupant response to ejection forces and could affect toe guide effectiveness. This is beyond the adverse effects directly attributable to thigh slap.

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2. Shortening upper and lower leg links (through Anthropometric limitations) to achieve seat-man compliance affords the rear occupant of the TF-18 aircraft the same protection as his counterpart in the front crew station (without Anthropometric limitations).

3. The proposed limitations should not affect foot-toe guide interaction.

4. It is anticipated that these limitations will exclude at most 15% of the population.

5. This can be reduced even further through upward seat adjustment when possible. This alternative should be approached with great caution.

6. The procedure recommended is shown in figure 23.

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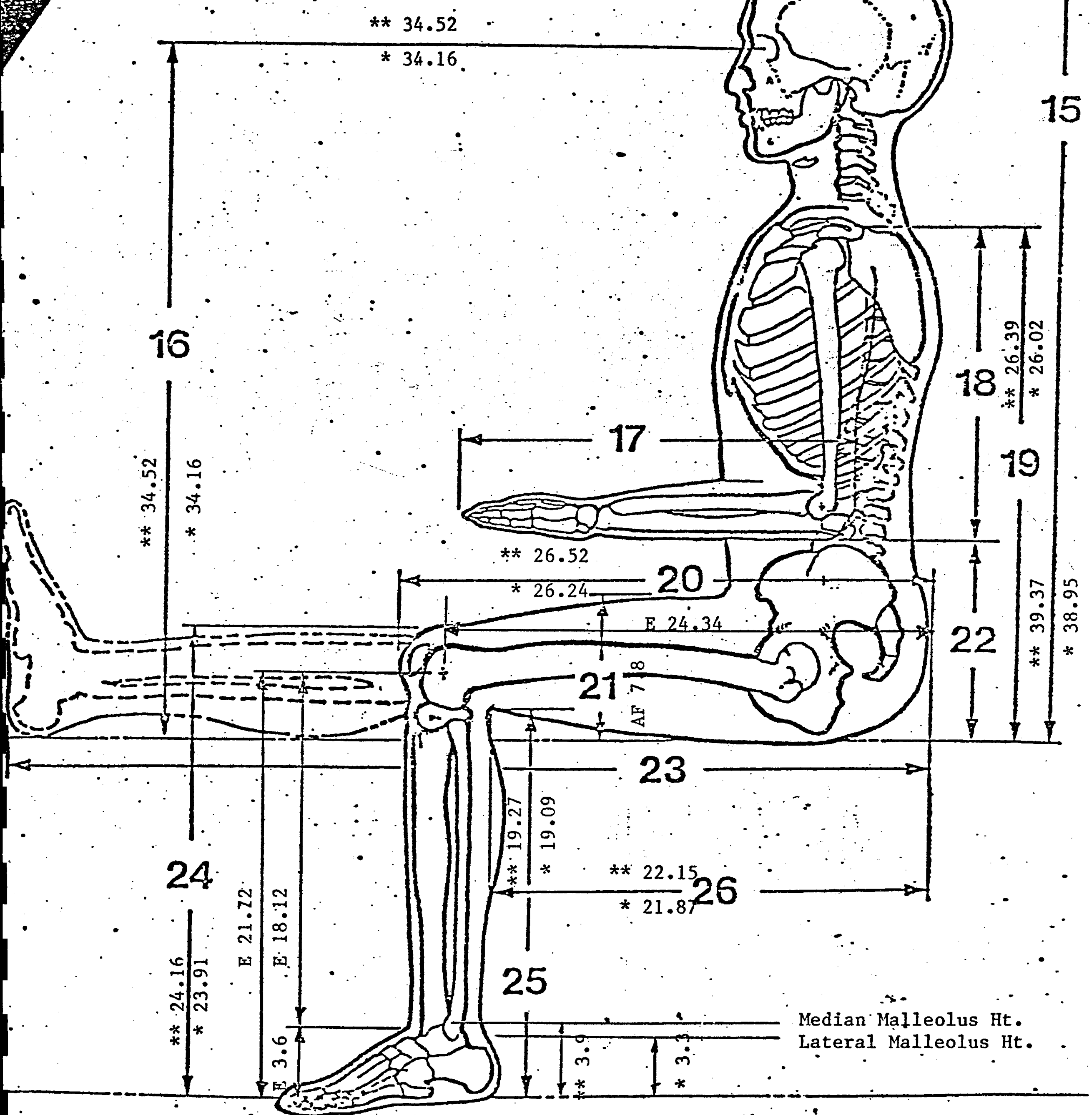
* 98th. Percentile

** 99th. Percentile

E Estimated

AF Air Force Survey (1967)



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* Naval Anthropometric Survey (1964)

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Published in NASA Ref. Pub. 1024, Anthro. Source Book, Vol. 2, 1978

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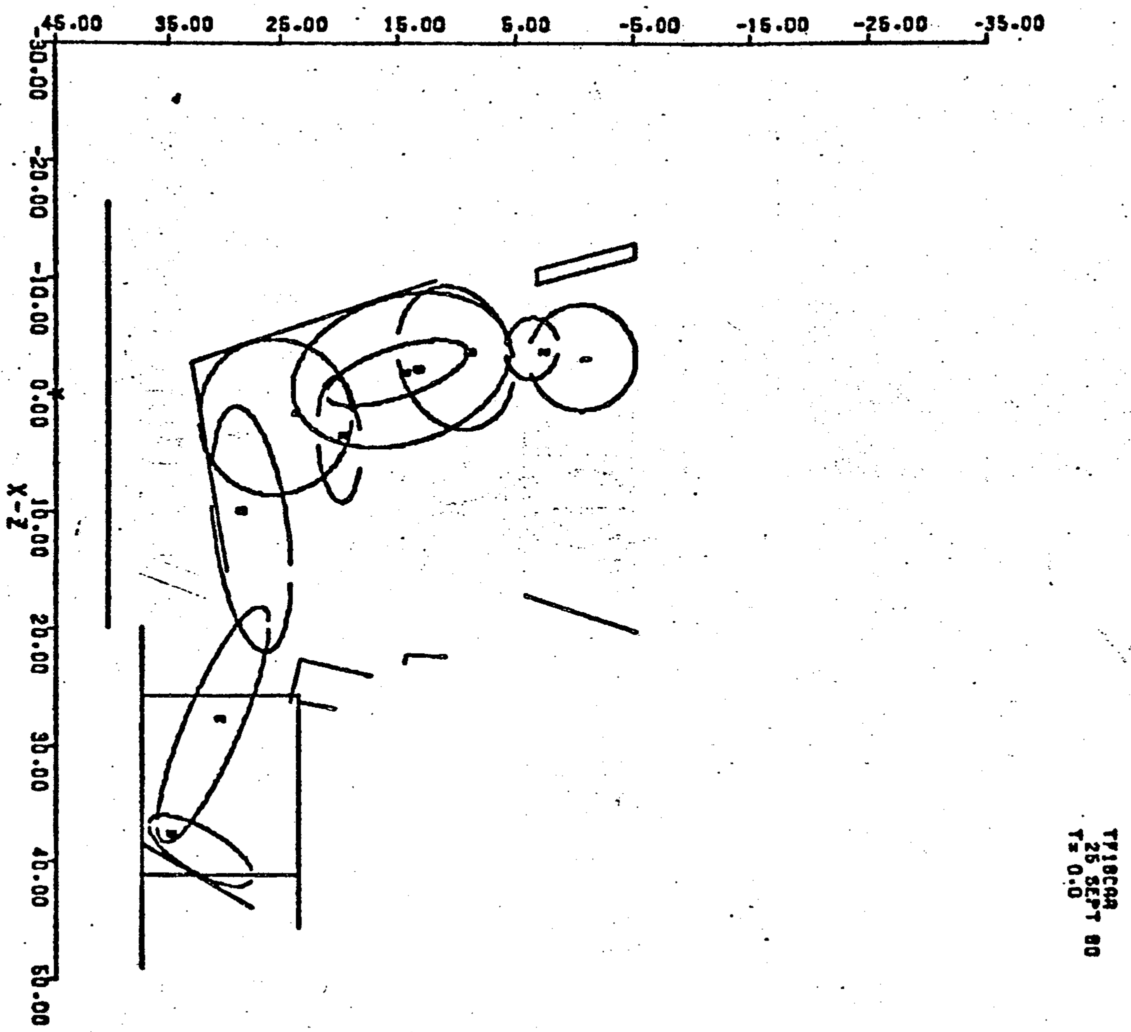

FIGURE 2A

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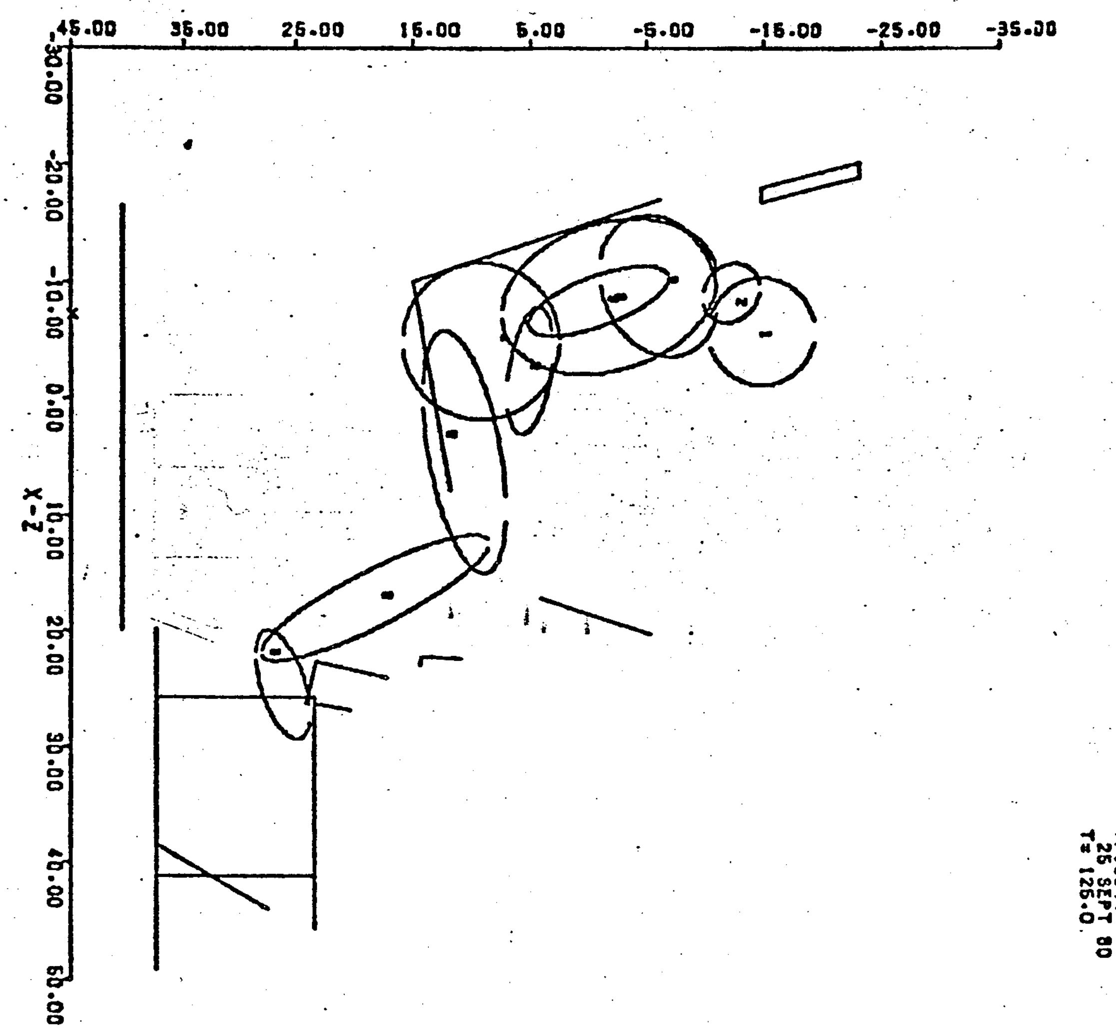

FIGURE 2B

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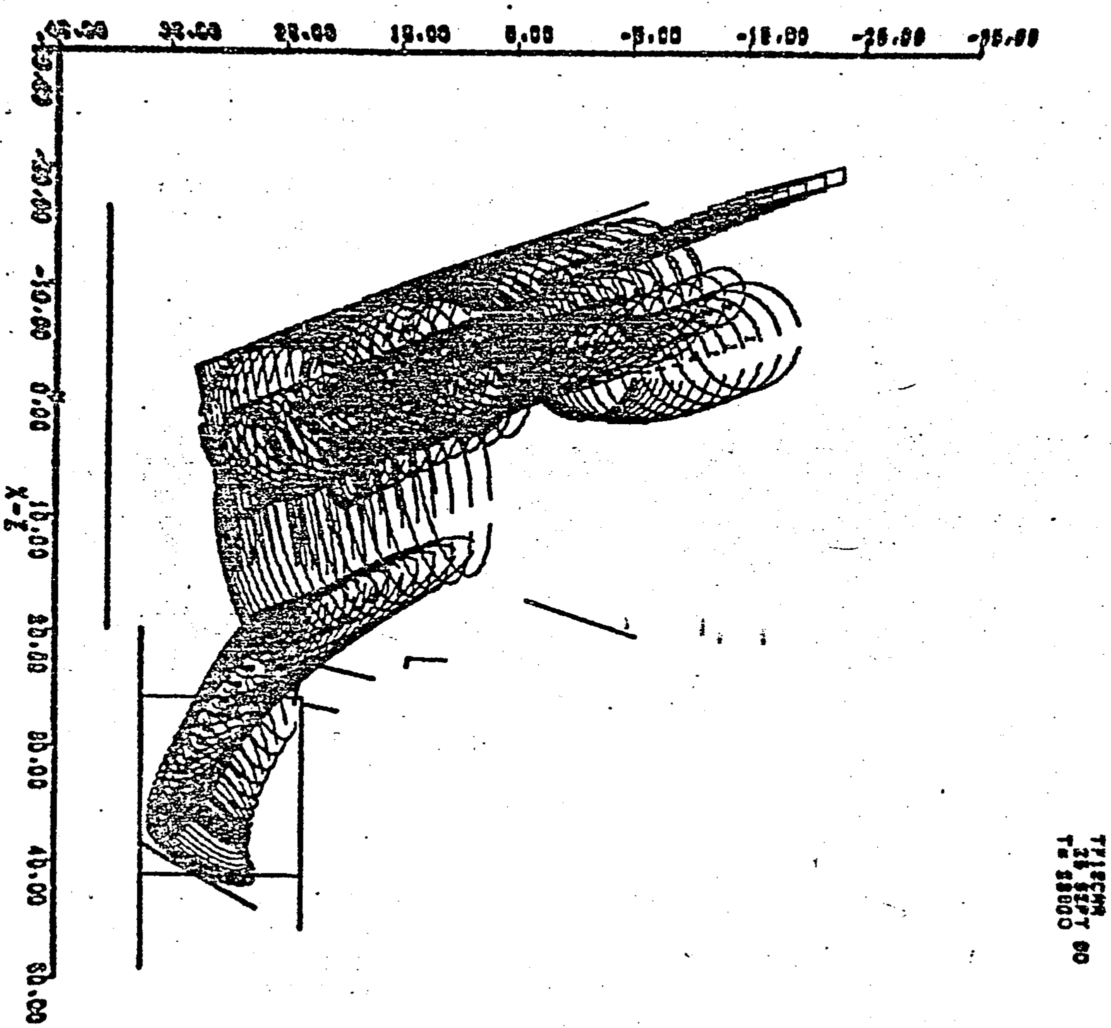

FIGURE 2C

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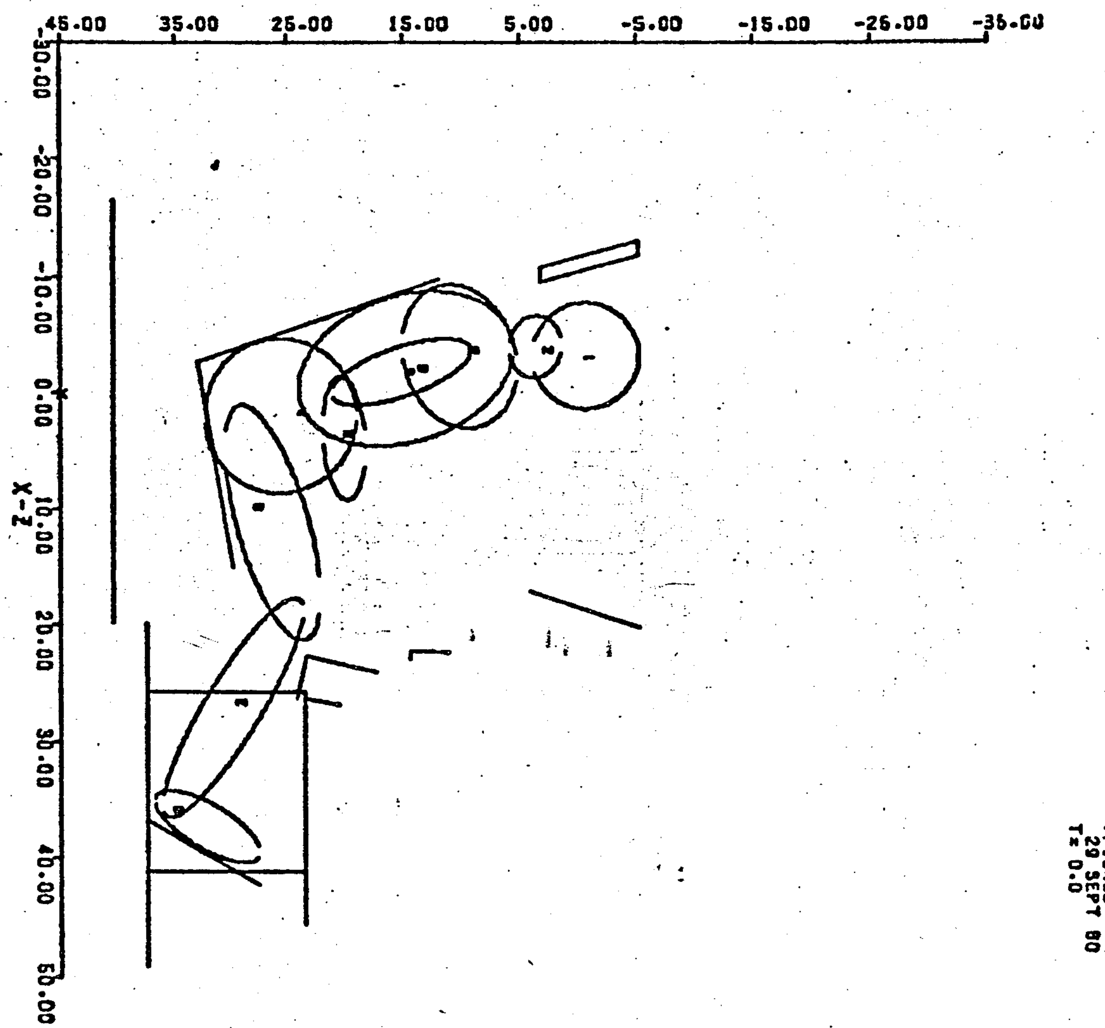

FIGURE 3A

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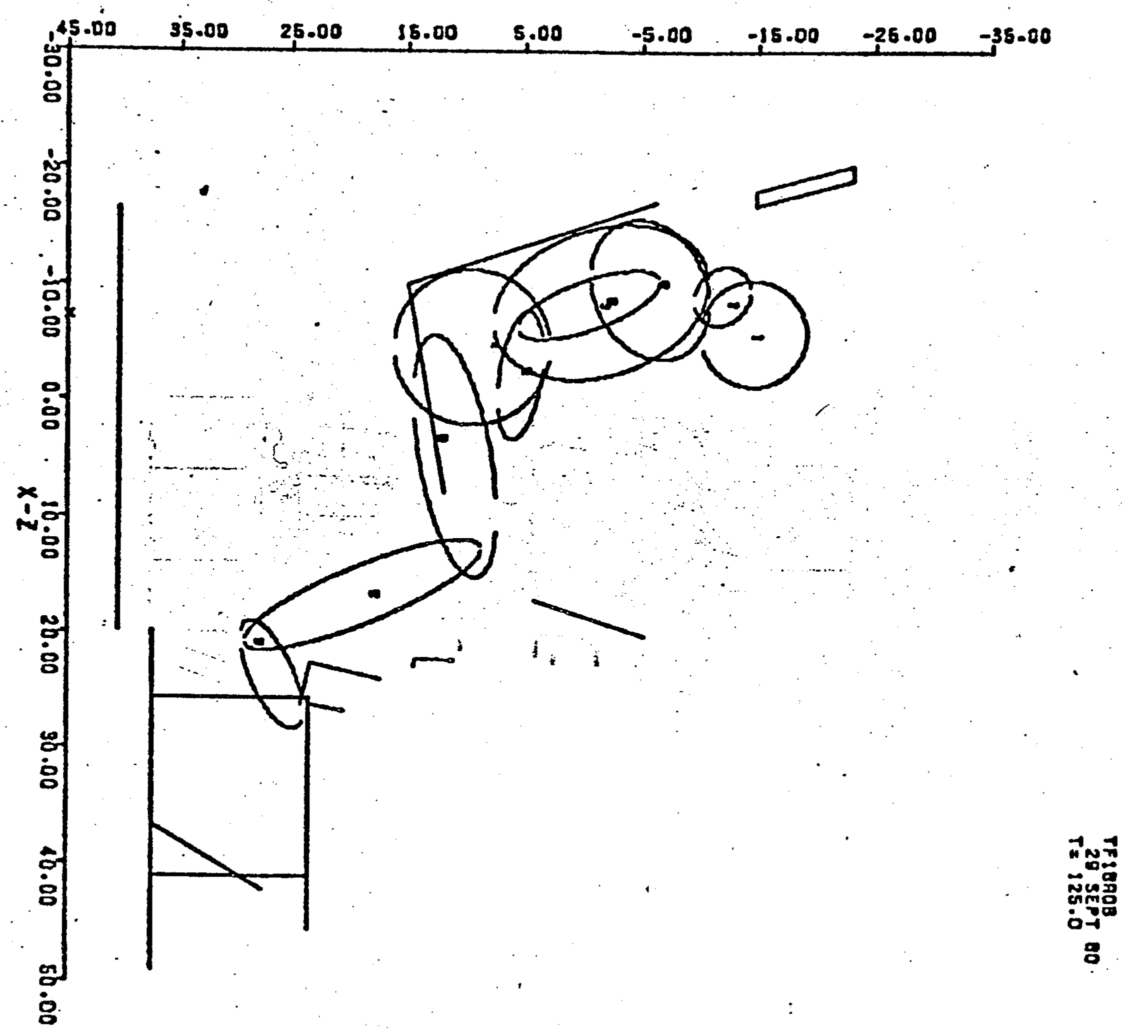

FIGURE 3B

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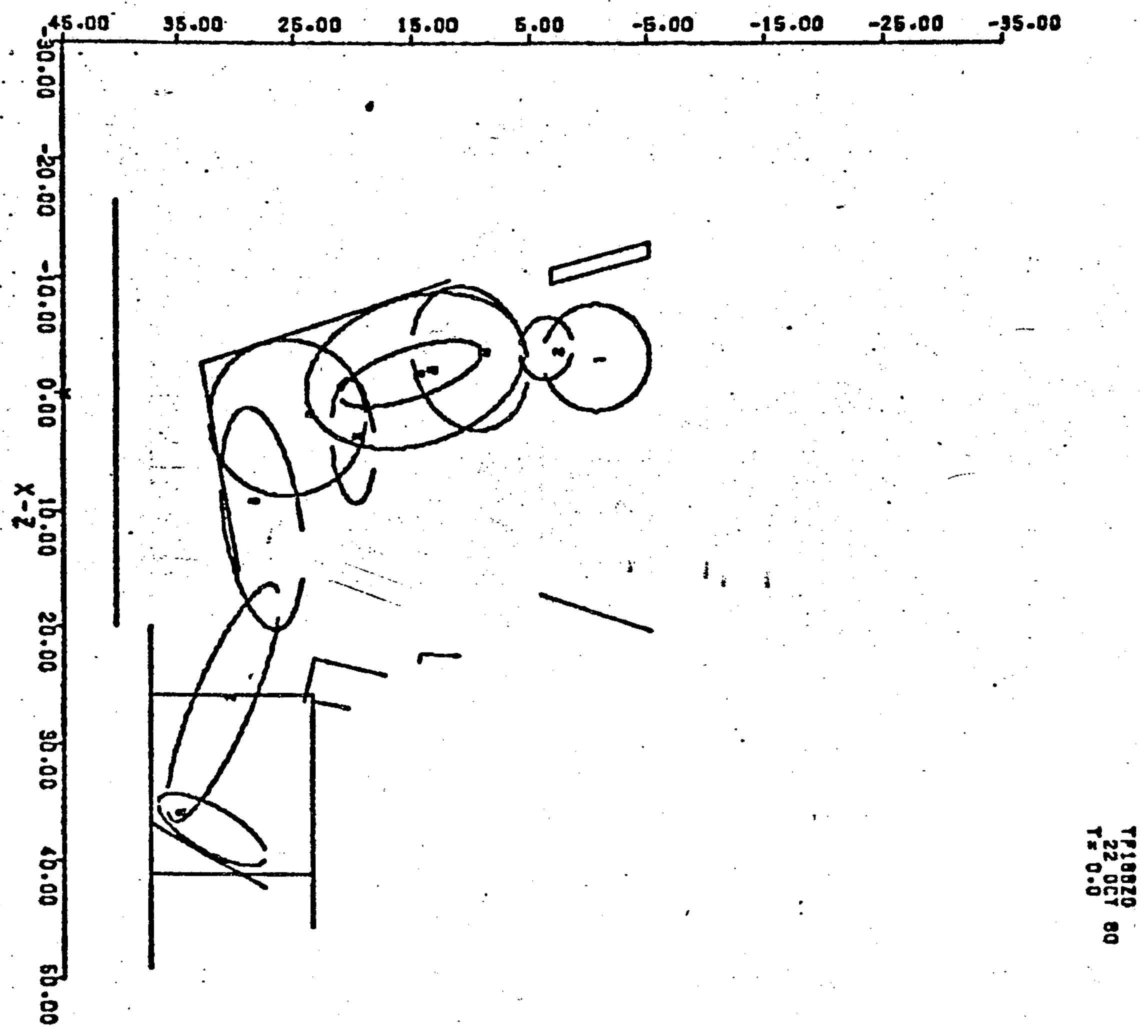

FIGURE 4A

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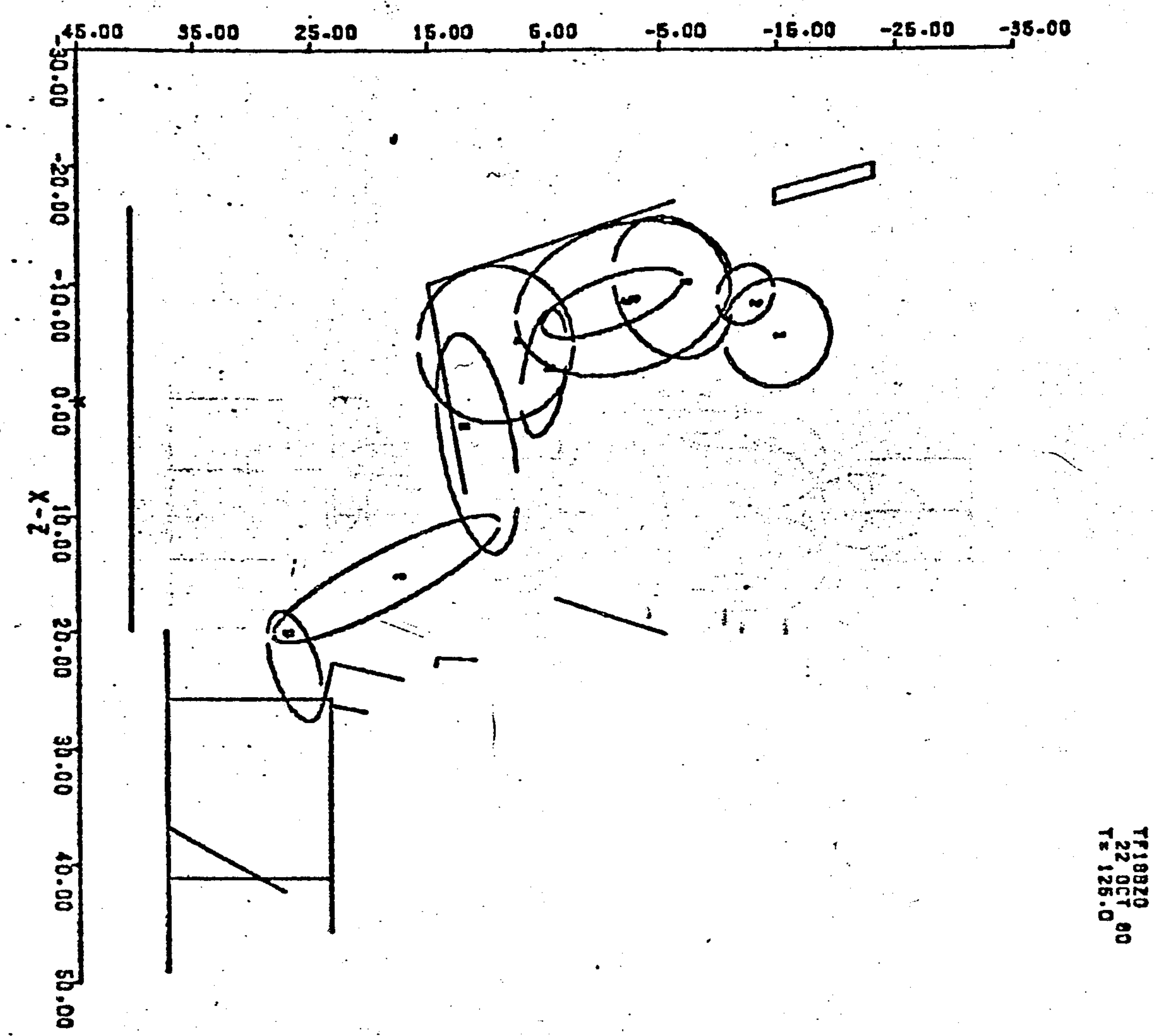

FIGURE 4B

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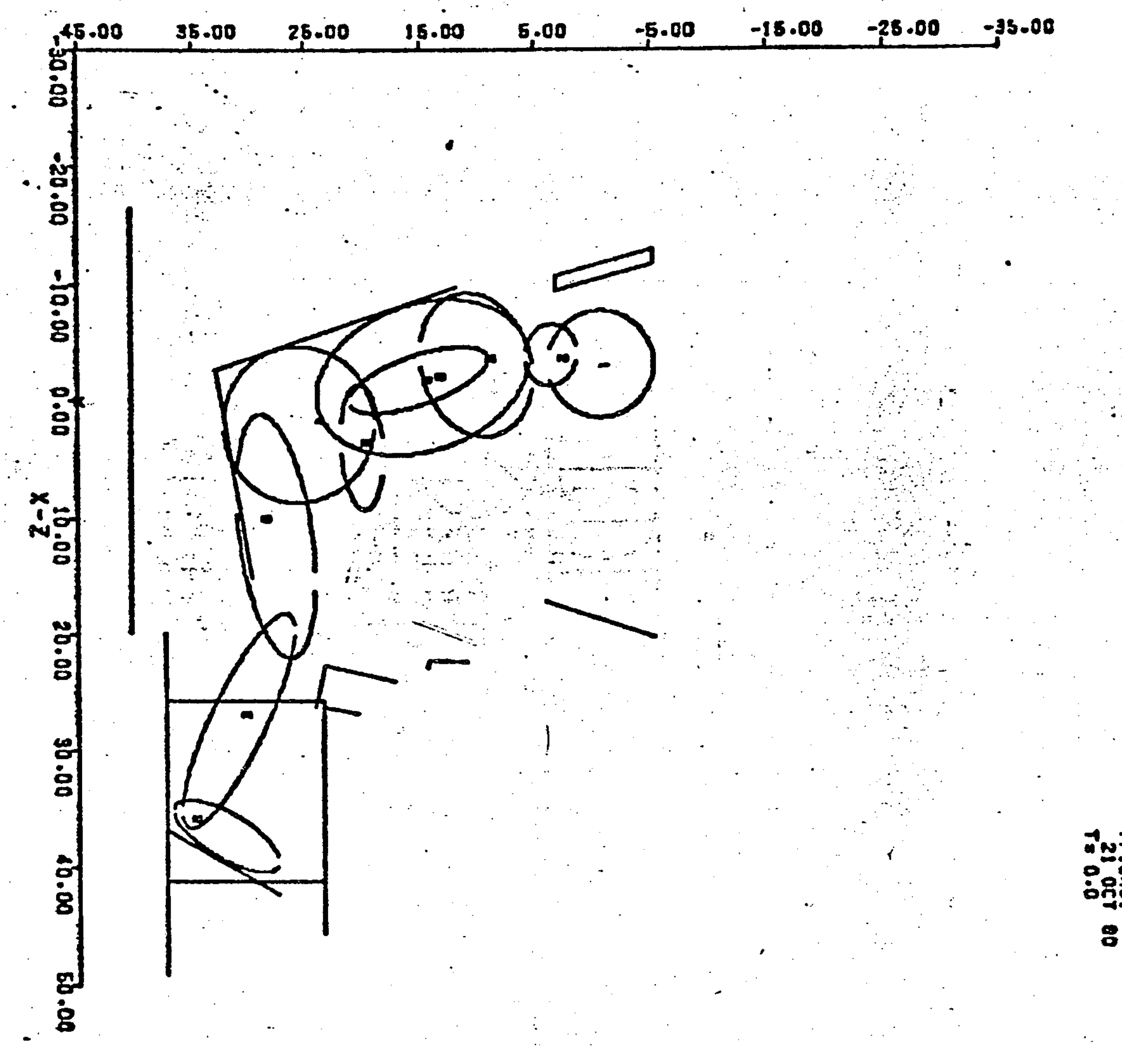

FIGURE 5A.

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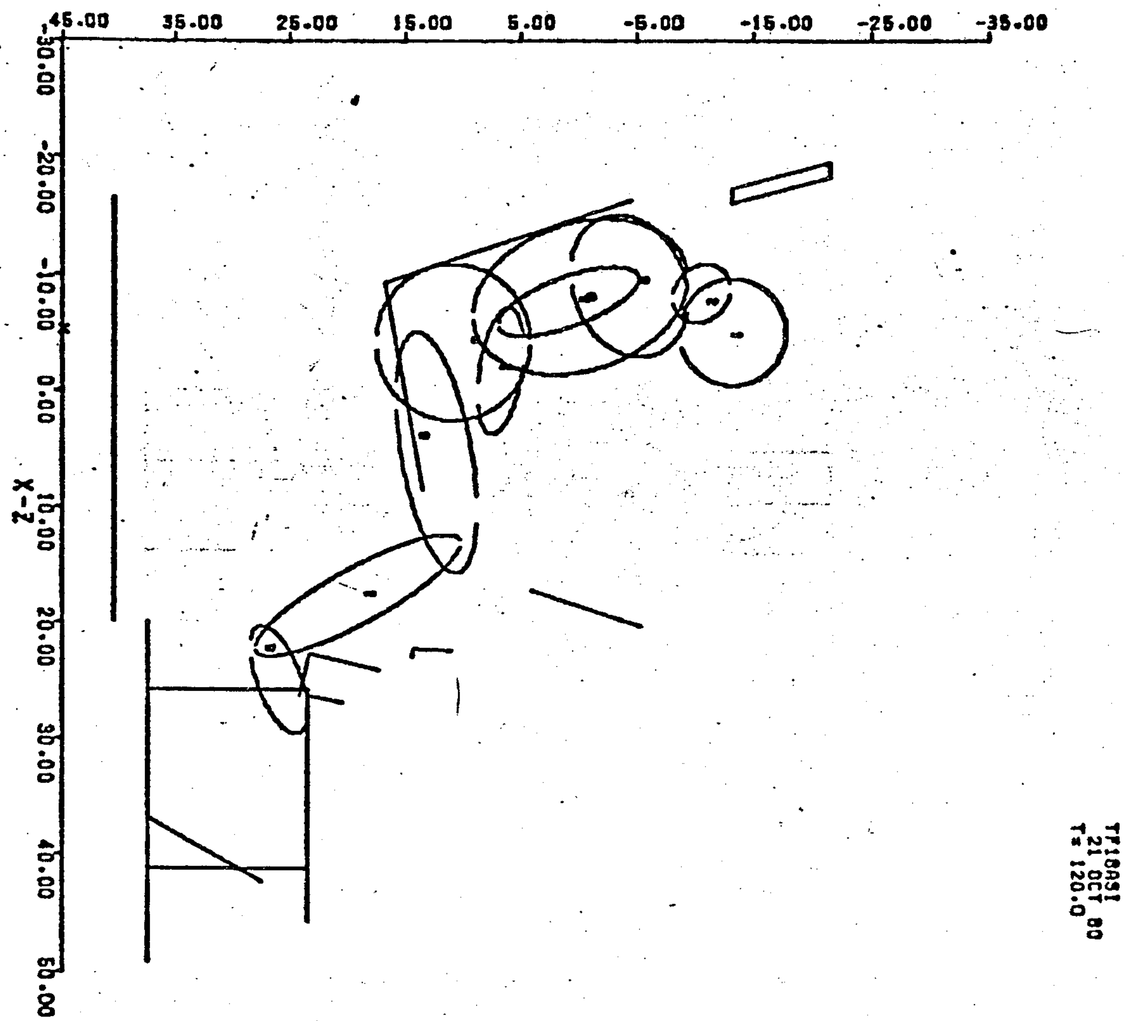

FIGURE 5B

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RUN 1F18COMP

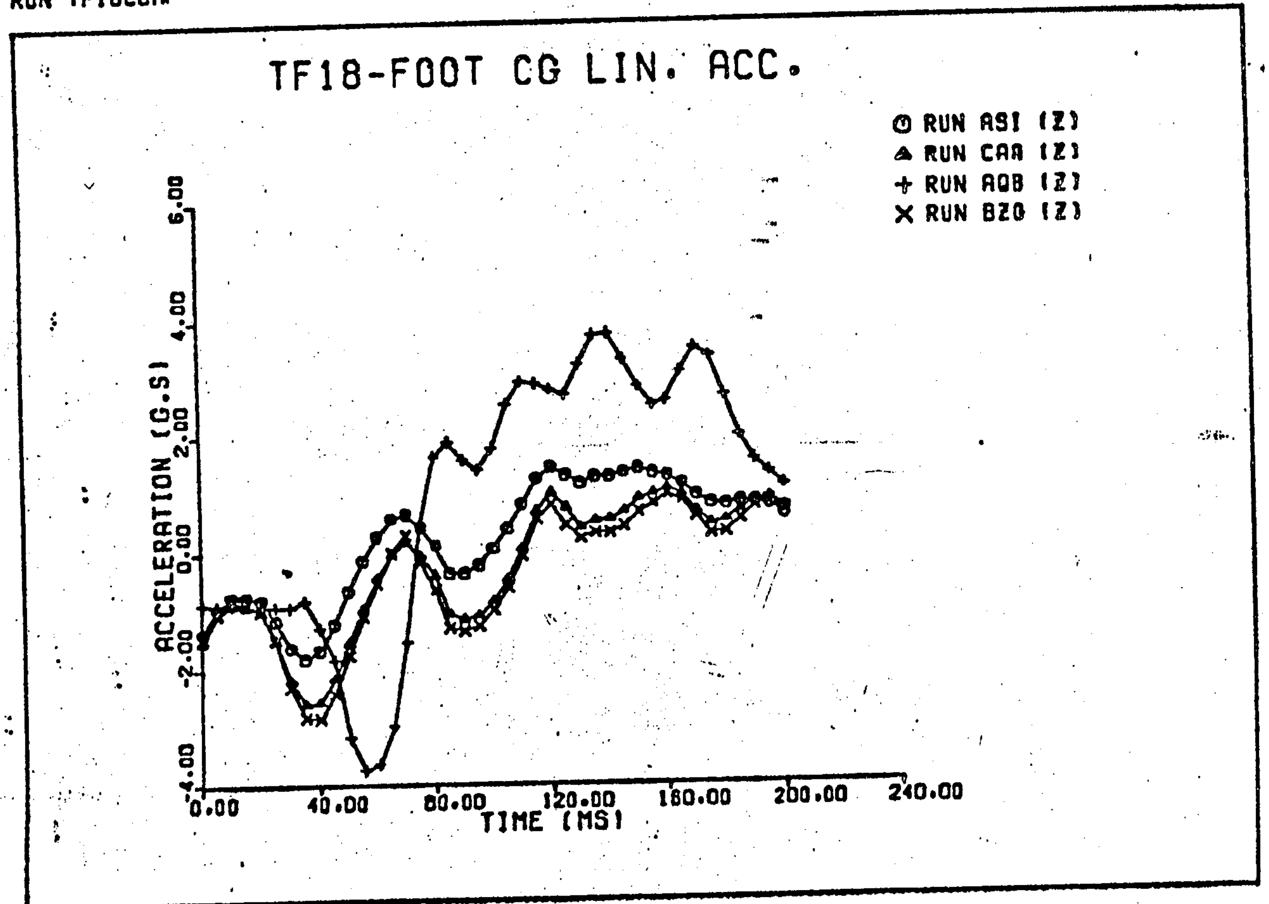

FIGURE 6

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RUN TF18COMP

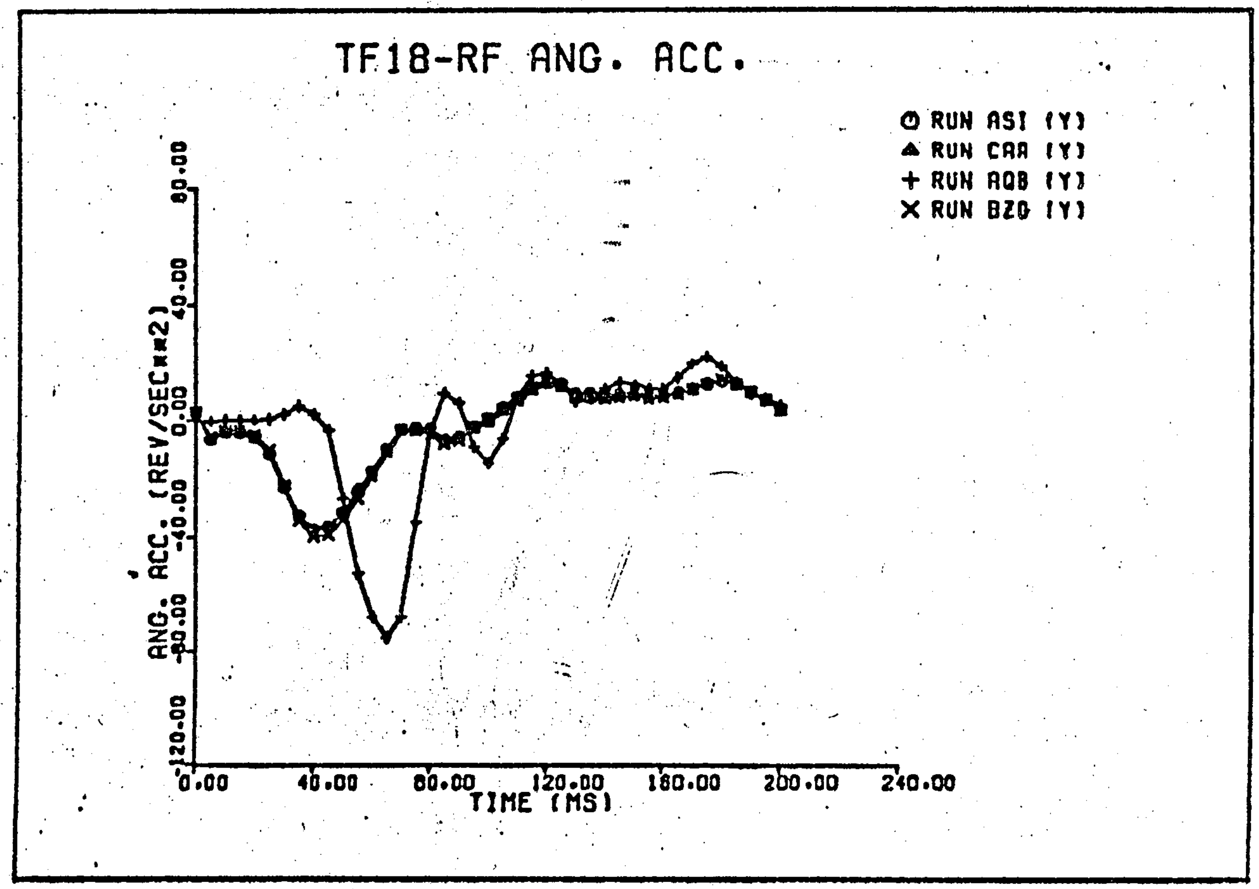

FIGURE 7

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RUN TF18COMP

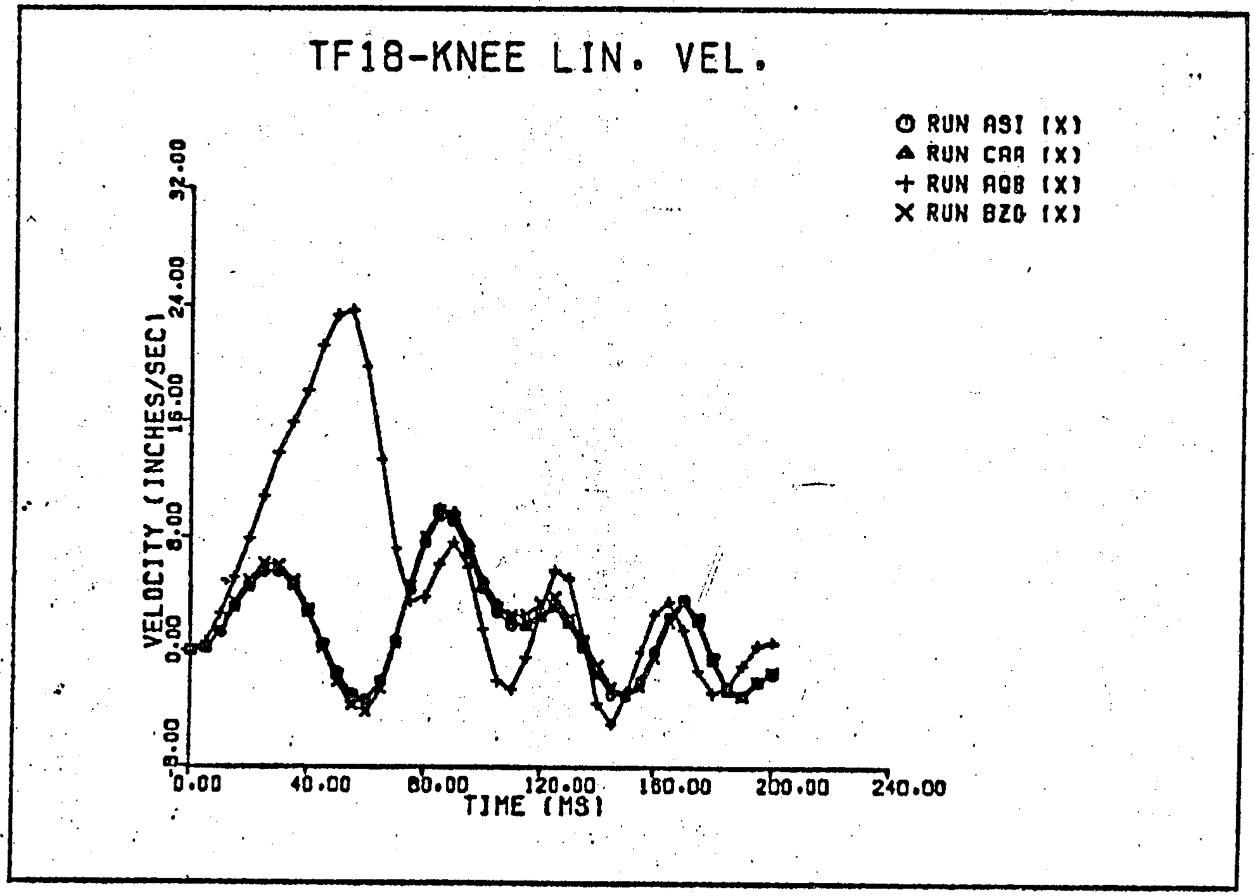

FIGURE 8

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RUN TF18COMP

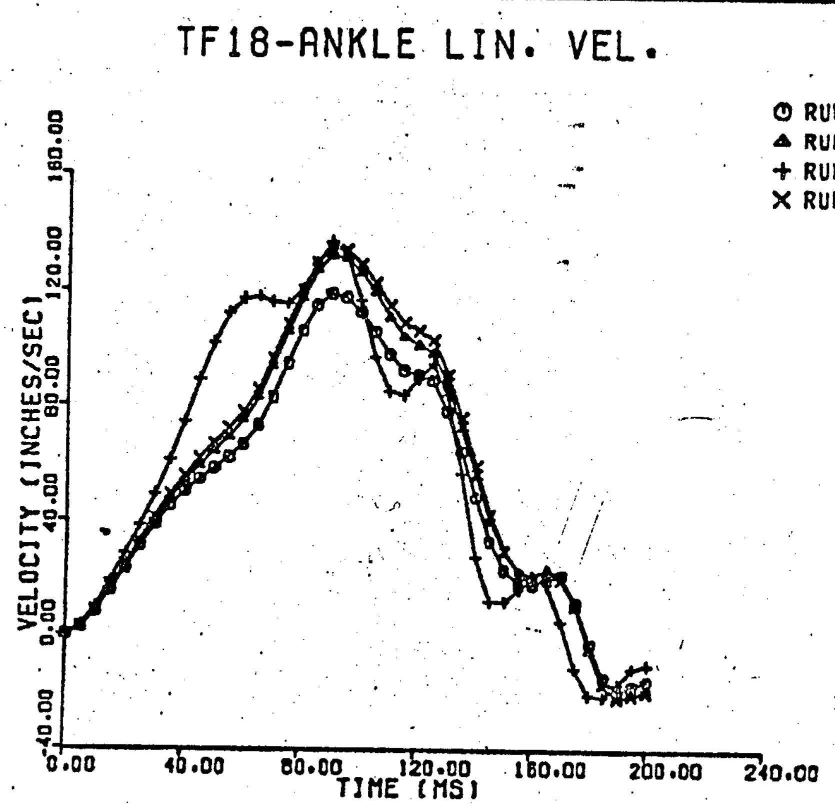

FIGURE 9

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RUN TF18COMP

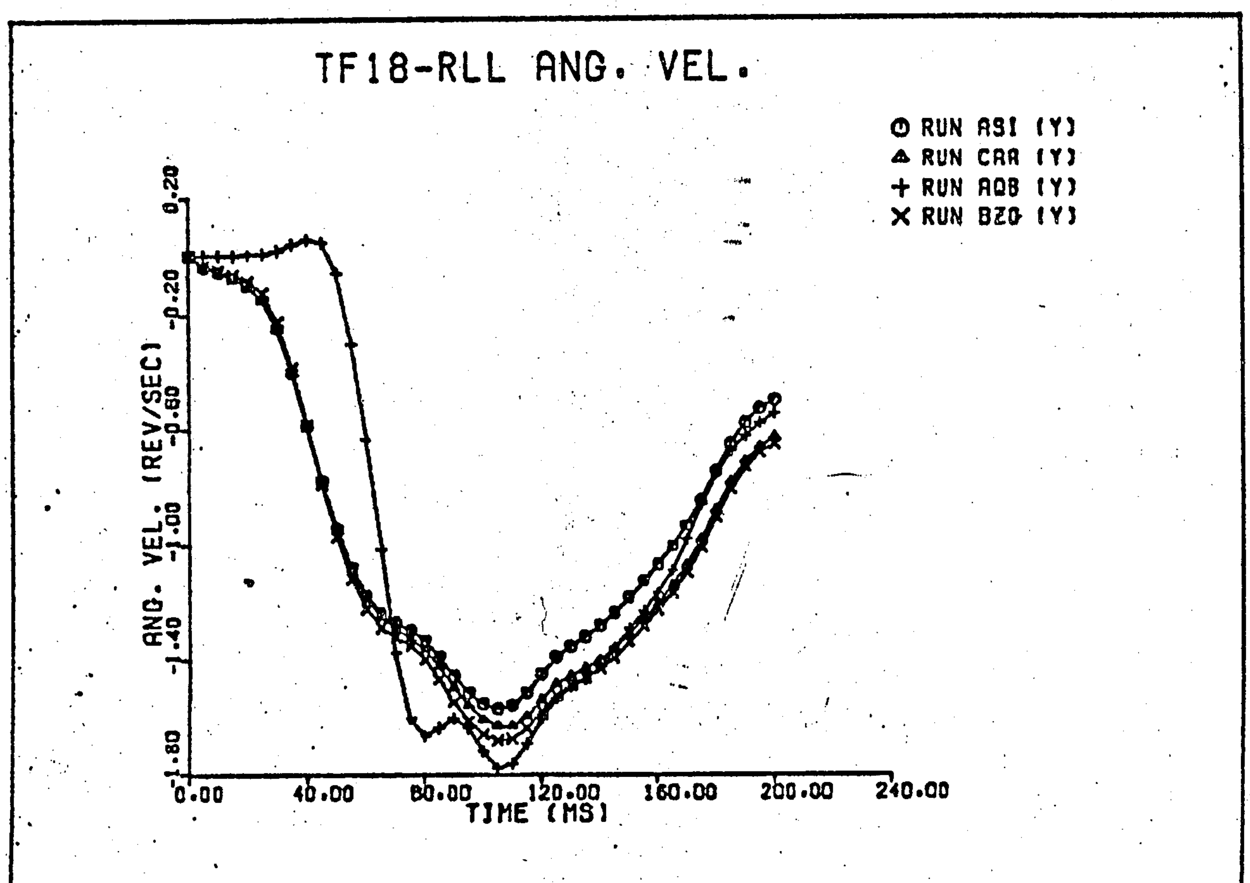

FIGURE 10

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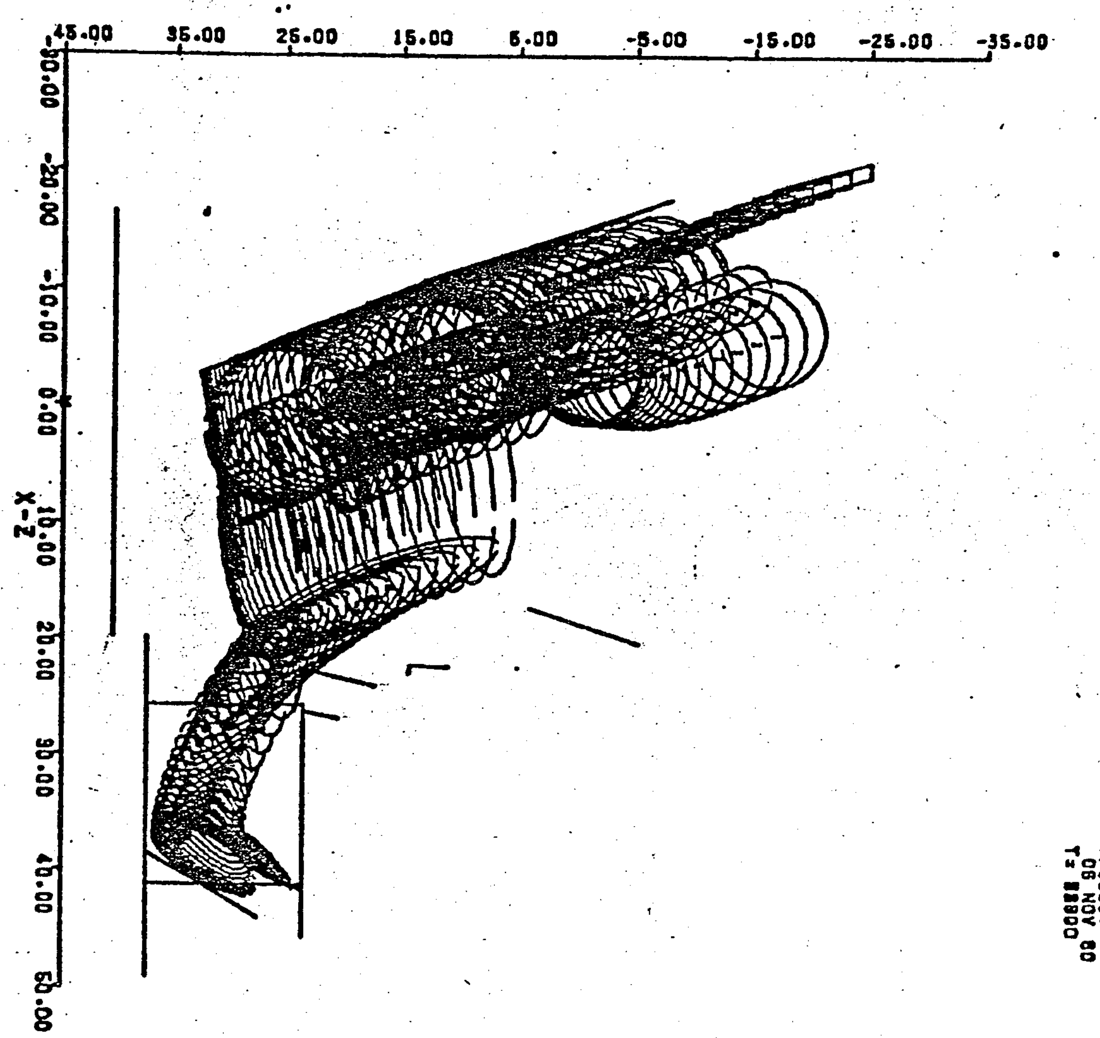

FIGURE 11

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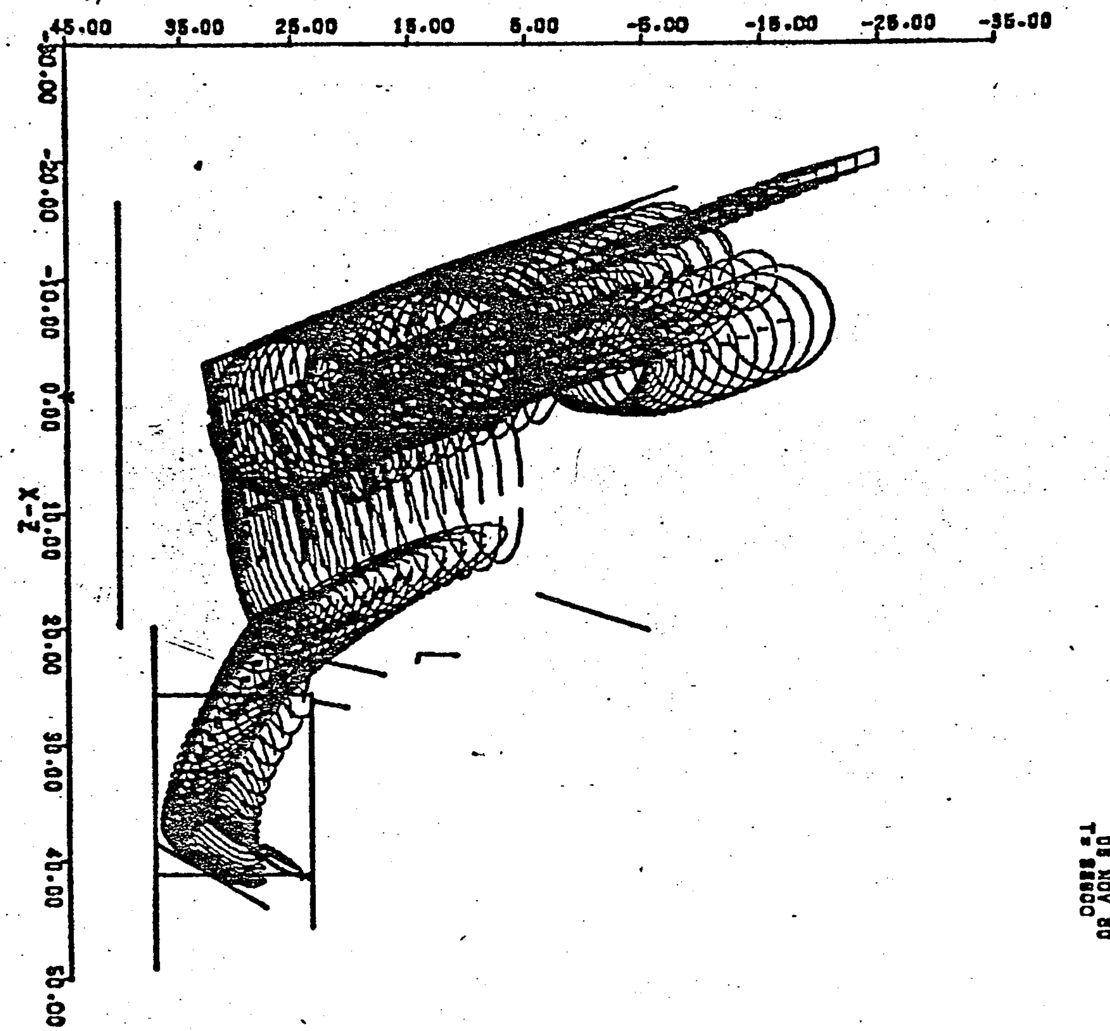

FIGURE 12

DRAFT

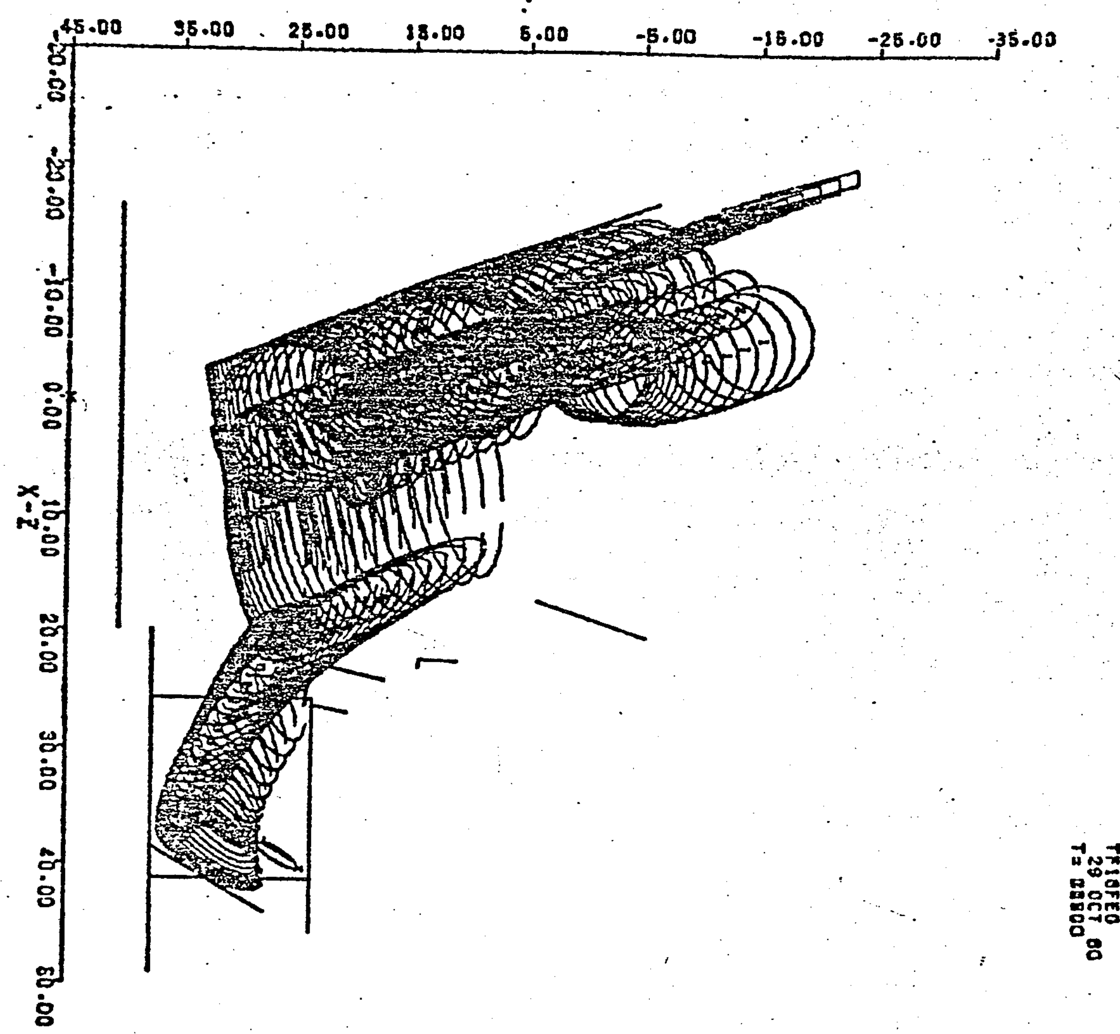

FIGURE 13

DRAFT

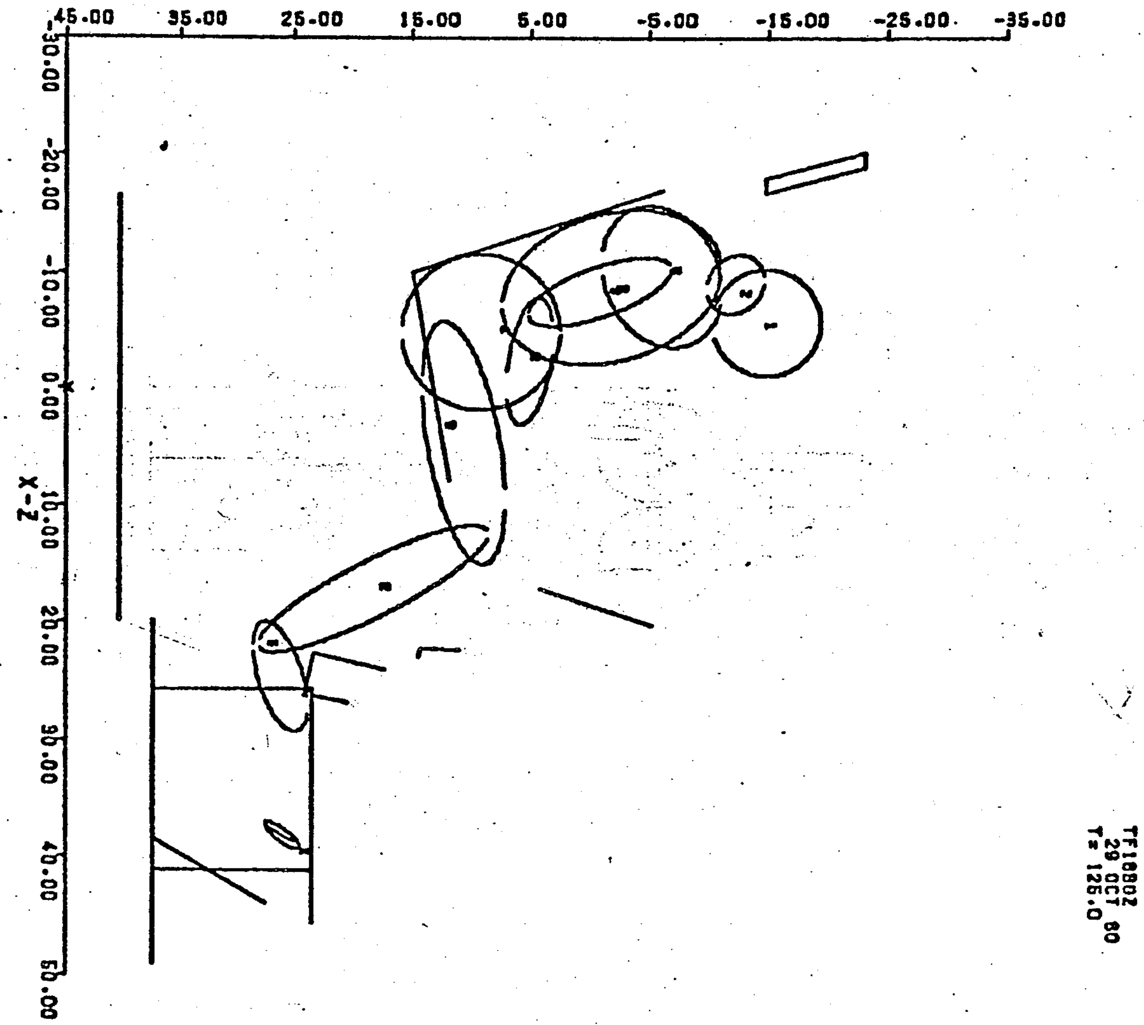

FIGURE 14A

DRAFT

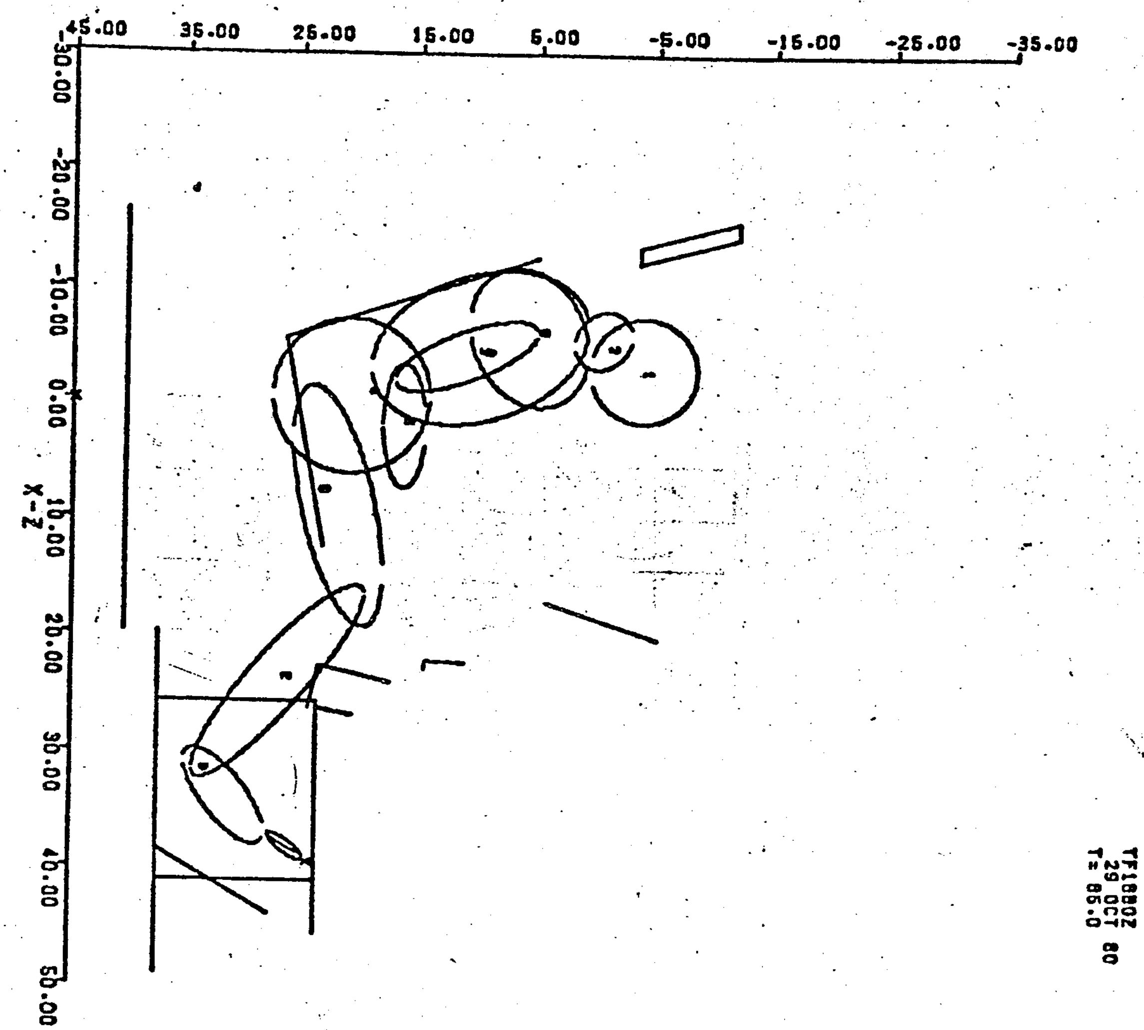

FIGURE 14B

DRAFT

RUN TF18COMP

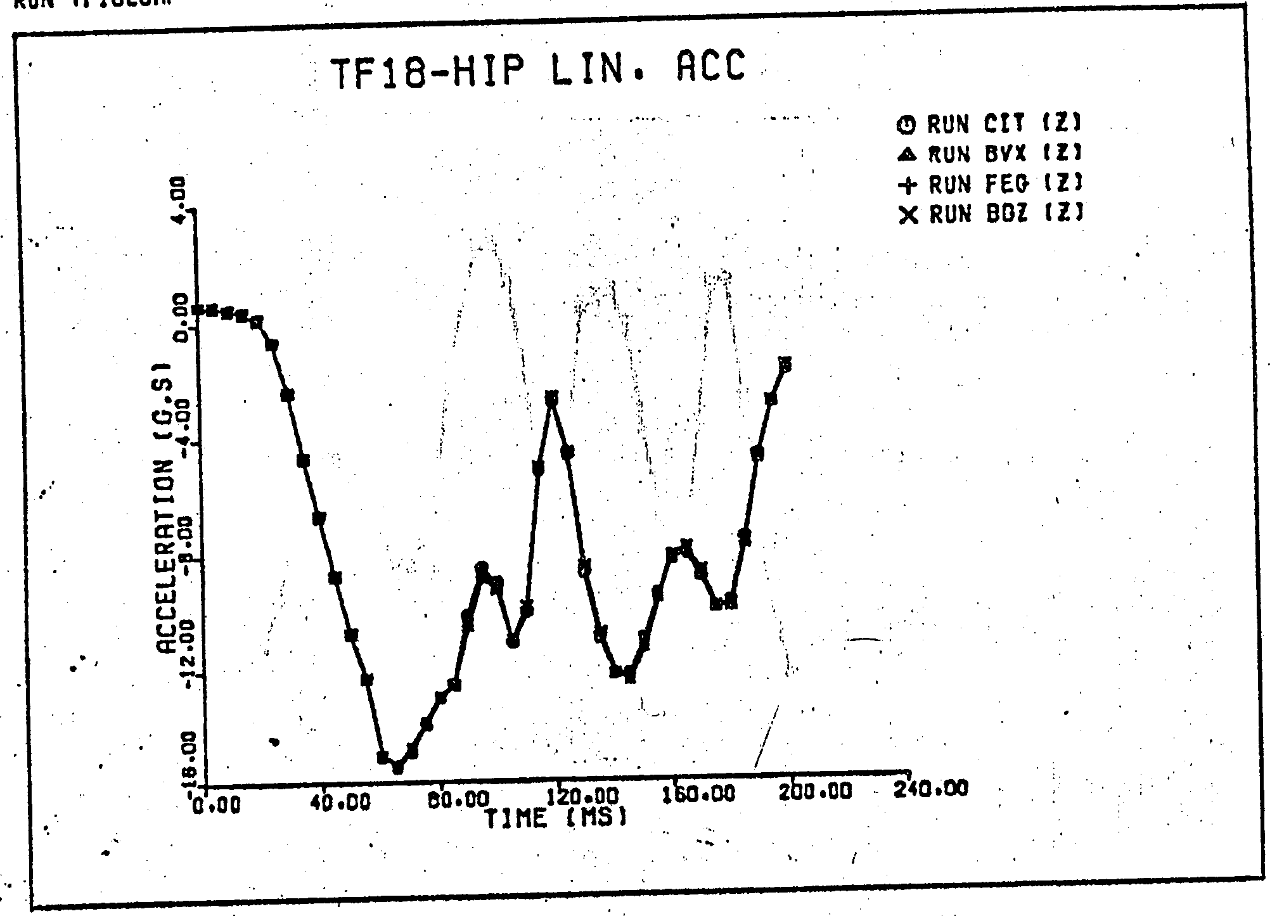

FIGURE 15

DRAFT

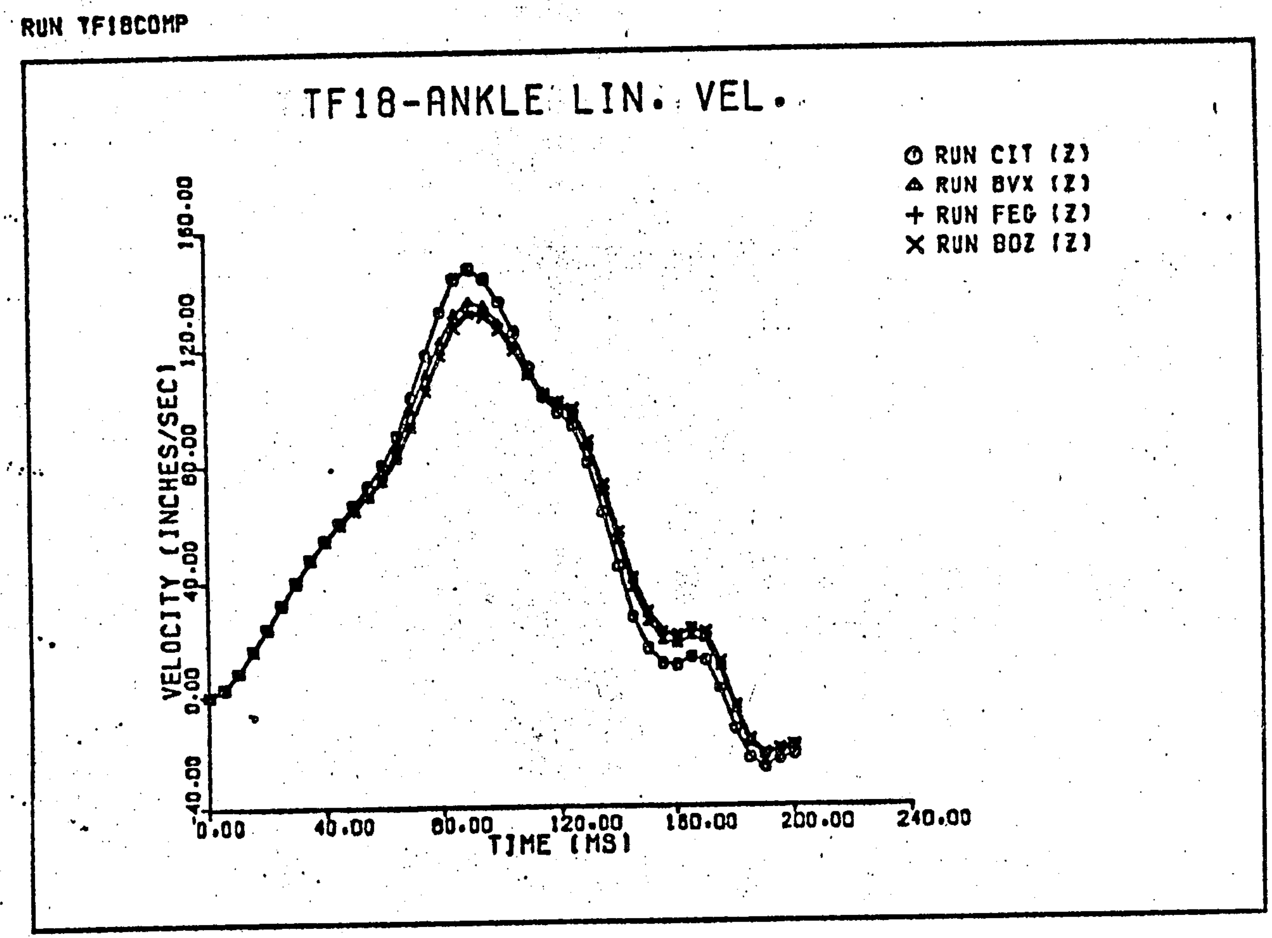

FIGURE 16

DRAFT

RUN TF18COMP

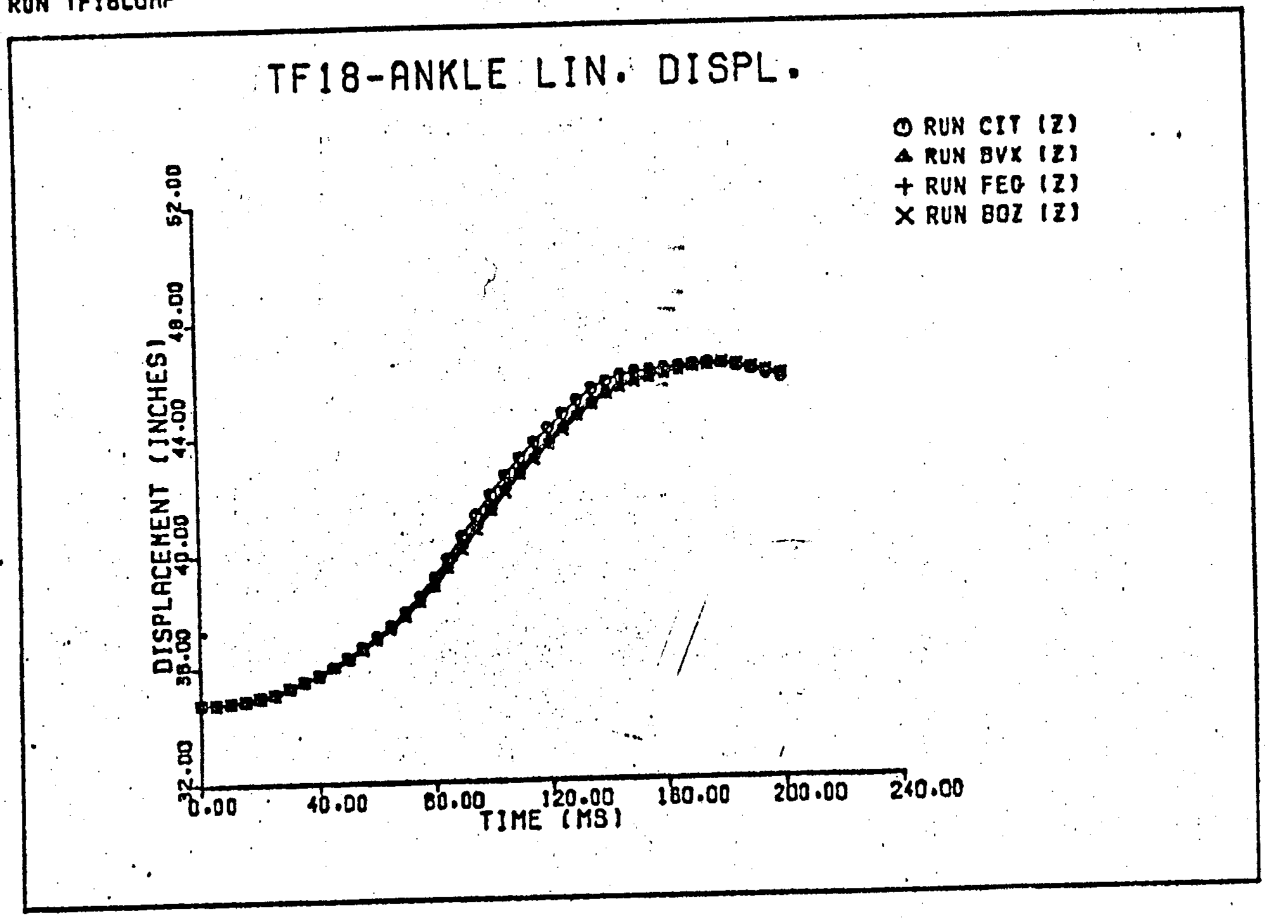

FIGURE 17

DRAFT

RUN TF18COMP

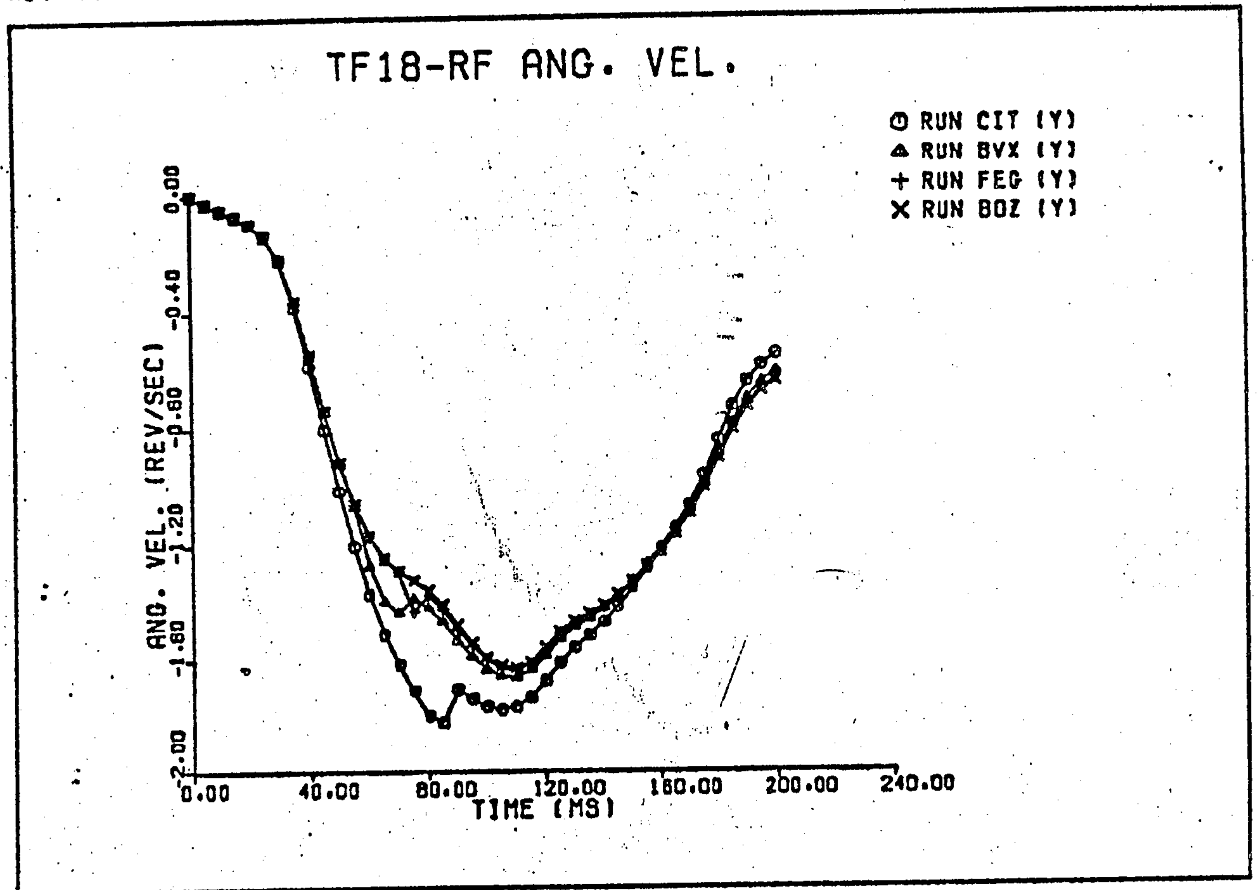

FIGURE 18

DRAFT

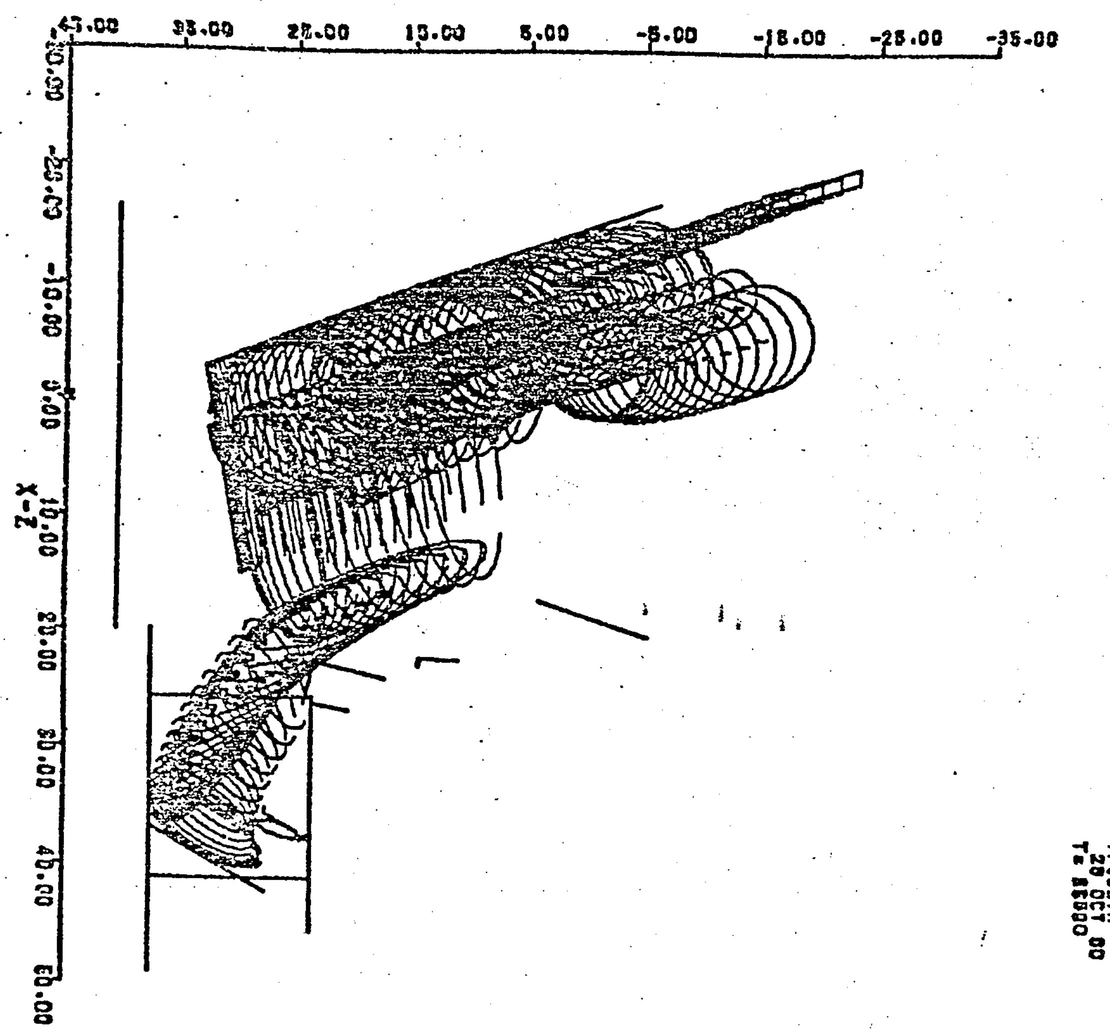

FIGURE 19

DRAFT

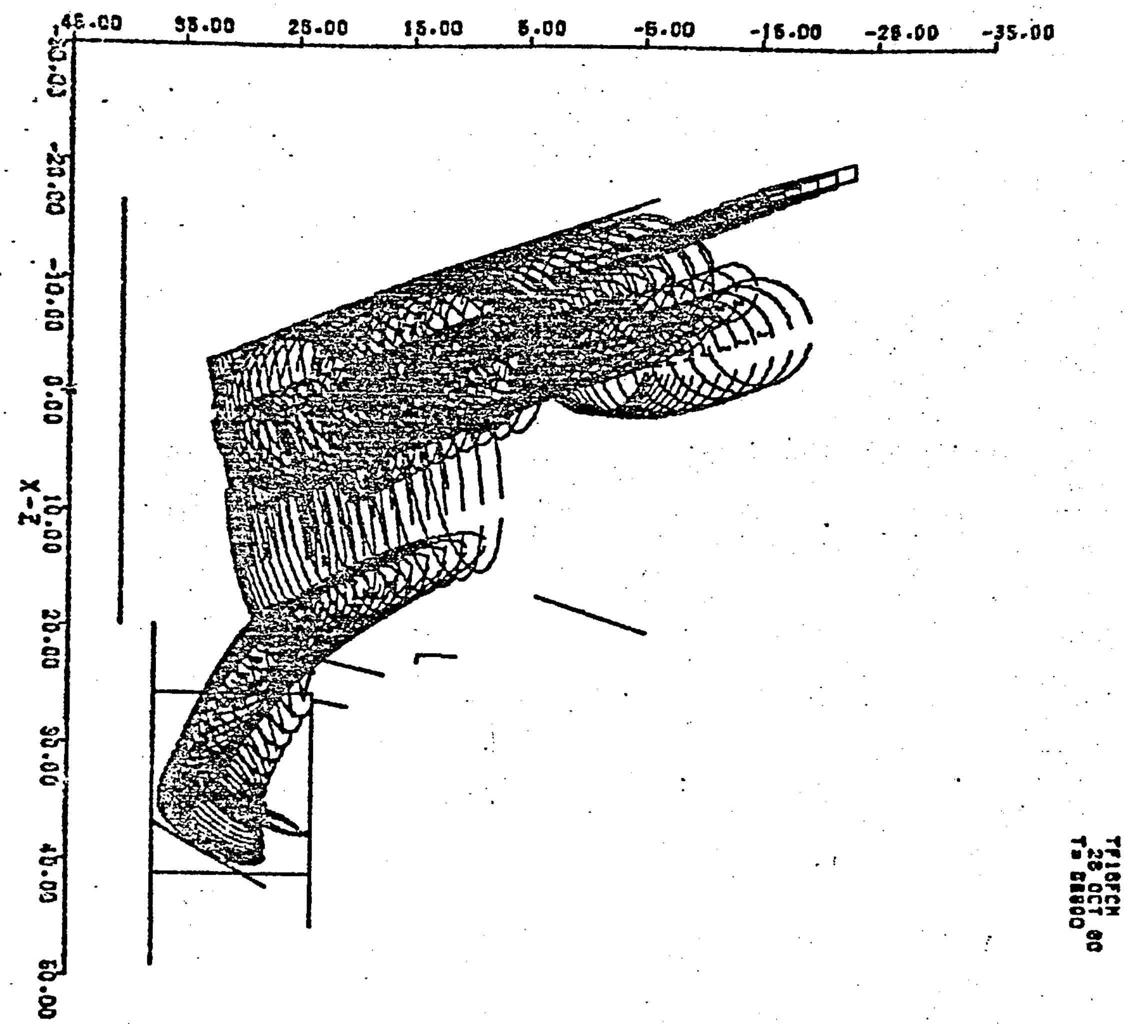

FIGURE 20

DRAFT

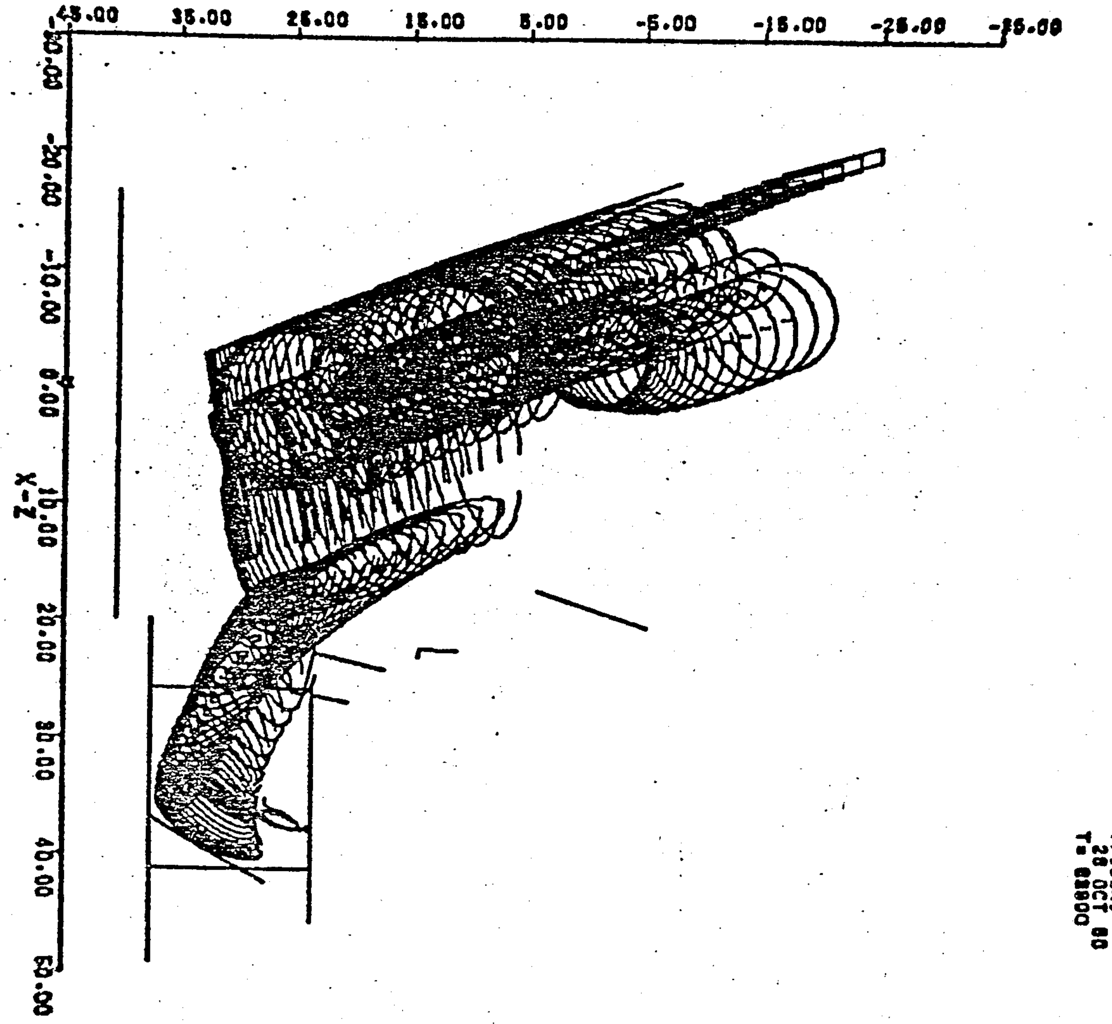

FIGURE 21

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Figure 22A

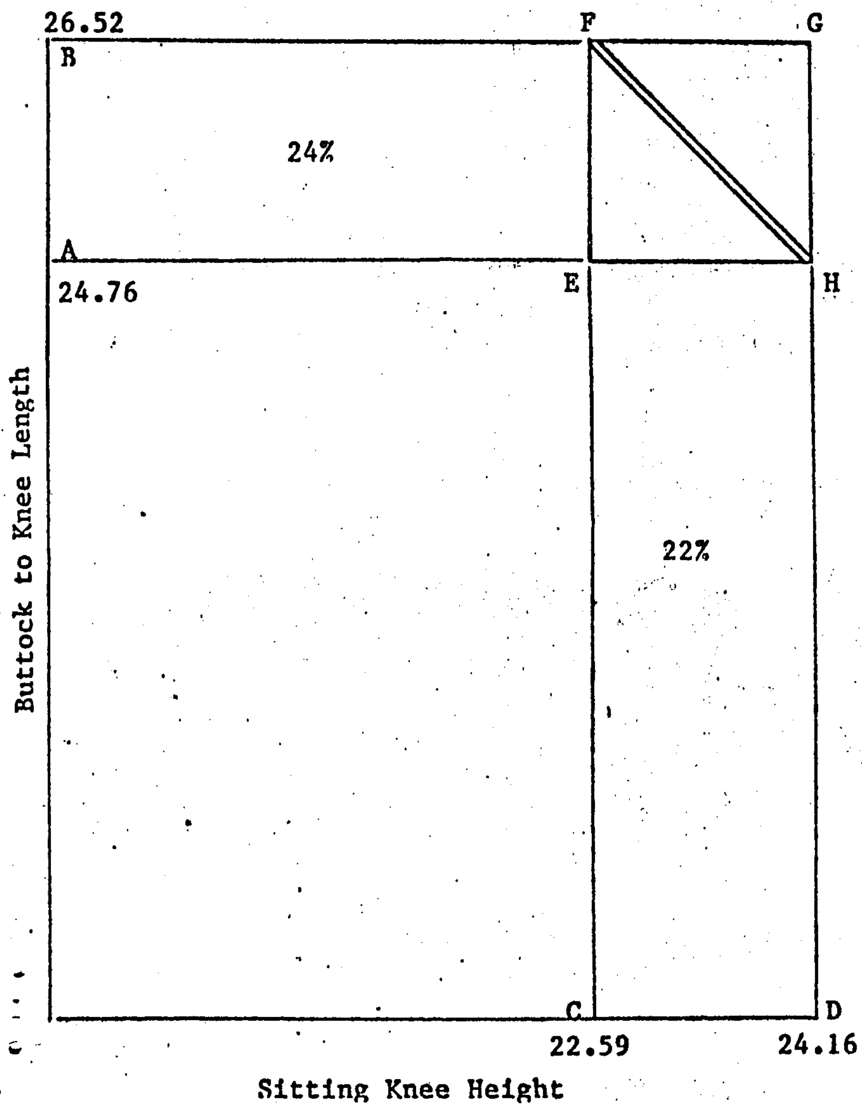
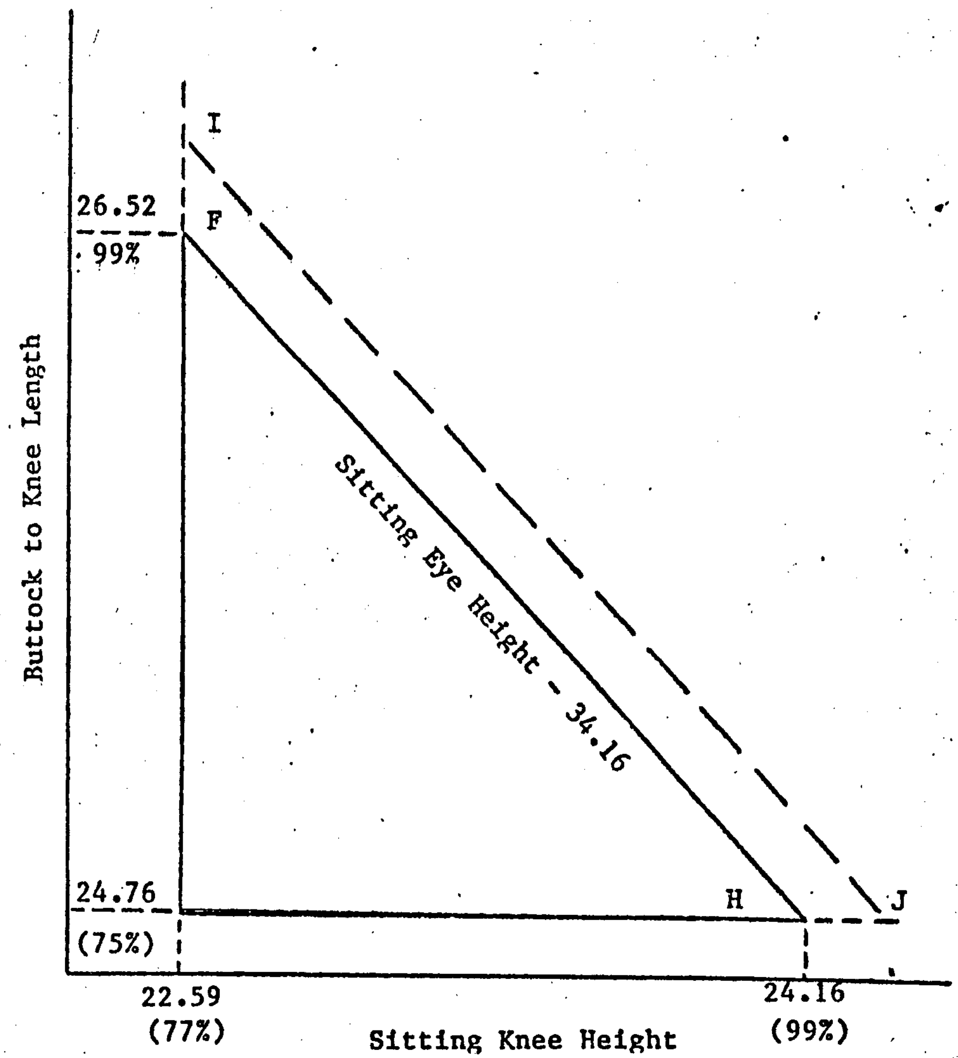


Figure 22B



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TF-18 ANTHROPOMETRIC LIMITATION.

1. Does subject qualify for the front crew station? (No anthropometric limitations for the front.) ** → NO — REJECT

YES ↓

2. Buttock to Knee Length < 75% ? → YES — ACCEPT

NO ↓

3. Sitting Knee Height < 77% ? → YES — ACCEPT

NO ↓

4. Do leg link lengths fall to the right of line FH (figure 22B) ? → NO — ACCEPT

YES ↓

5. Sitting Eye Height < 90% ? → NO — REJECT

YES ↓

6. Seat height adjustment procedure.

   a. Sit occupant in aircraft and adjust seat upward to have eyes coincident with Design Eye Plane.

   b. Assure that shoulders are not above shoulder harness take up reel.

   c. Without adjusting seat, allow occupant to push rudders (adjust forward) forward as far as possible to get thighs down on seat pan. If adjustment limit (maximum forward) is reached before thigh-seat pan contact is attained, REJECT.

** This deals only with sitting height, buttock to knee lengths and sitting knee height.

Figure 23

REPORT DOCUMENTATION PAGE

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13. ABSTRACT *(Maximum 200 words)*

This publication provides documentation to identify the differences in ejection response of large individuals in the front vs. the rear crew stations. In addition, can anthropometric limitations be specified such that the possible response differences can be obviated.

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